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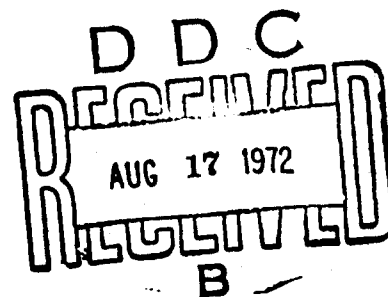


SMALL-SIZED SOURCES OF CURRENT

BY

V. A. Orlov

USSR



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SMALL-SIZED SOURCES OF CURRENT

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TABLE OF CONTENTS

	Page
Introduction	1
Chapter One: Basic Characteristics of Sources of Current	4
Electromotive Force	4
Voltage	5
Internal Resistance	5
Capacitance	7
Specific Characteristics	13
Efficiency	14
Self-Discharge	16
Service Life and Shelf Life	17
Resistance to Impact and Vibration Loads	18
The Operating Temperature Range	23
The Designating of Current Sources	23
Chapter Two: Chemical Sources of Current	26
A. Voltaic, Fuel and Biological Cells	29
Manganese-Zinc Dry Cells and Batteries	29
Mercury-Zinc Cells and Batteries	36
Wet Cells and Batteries	51
Fuel Cells	60
Biological Cells	63
B. Storage Batteries	70

Table of Contents

	Page
Cadmium-Nickel (EN) Sealed Storage Batteries	70
Circular Cadmium-Nickel Storage Batteries	70
Cylindrical Sealed Cadmium-Nickel Storage Batteries	77
KMG Sealed Cadmium-Nickel Storage Batteries	80
Lamellless Cadmium-Nickel Storage Batteries	88
The Nickel-Zinc (NTs) Alkaline Battery	97
Silver-Zinc (STs) Storage Batteries	100
Silver-Cadmium (SK) Batteries	110
 Chapter Three: Semiconductor Sources of Current	 115
Thermoelectric Sources of Current	123
Photoelectric Source of Current	129
Thermoemission (Plasma) Sources of Current	138
Thermophotovoltaic Converters	142
Ferroelectrics	143
Electrets	145
 Chapter Four: Atomic Source of Current	 147
Atomic Sources of Current	147
 Chapter Five: Operation of Sources of Current	 152
Battery Chargers	156
Electrolytes	163
Methods for Charging Batteries	167
Charging and Regenerating Voltaic Cells and Batteries	172
Certain Malfunctions of Batteries and Ways to Eliminate Them	174
Repair of Lamellless Cadmium-Nickel, Silver-Zinc, Sealed Circular and Cylindrical Batteries	174
 Appendices:	
1. Table of Electrochemical Potentials	180
2. Glues and Resins Used for Repairing Battery Containers	182
 Bibliography	 183

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Annotation

The book describes the converters of various types of energy into electrical. The book describes the operating principles, design, technical and operating characteristics of modern autonomous sources of current: chemical (cells and storage batteries), semiconductor, atomic and other.

Reference material is given on the sources of current produced by Soviet industry, as well as the methods of operating them for the purpose of helping the reader to solve the problem of choosing the required source of current.

The book is designed for military specialists handling autonomous sources of current, as well as for engineers and technicians working in the area of radioengineering and electronics.

The book has been written using materials from Soviet and foreign press sources.

INTRODUCTION

The birth date of the first current source can be considered the day when the Italian physician Luigi Galvani, in working with a frog which had been dissected on a zinc-topped table, detected the contraction of its foot muscles in touching it with a copper tweezers.

However, archaeologists consider that chemical sources of current were used far back in antiquity, around 5000 years ago, in applying gold and silver surfaces to metal ornaments.

Clay vessels found in Iraq with copper containers and iron cores inside covered with an oxidized metal layer are reason to assume that ancient voltaic cells with an electrolyte in the form of citric or acetic acid could have produced an electric current with a voltage of around 0.5 volts.

The chemical sources of current discovered in the 18th and 19th centuries are characterized by a long time gap between creation and application. Around 50 years passed from the first voltaic batteries invented by Volta in 1799 before the sources of current developed by him and other scientists found application in galvanic equipment, lighting, the telegraph and mining, and only 100 years later did they begin to be used in the telephone and radio.

Until the inventions of "machine" electricity, dynamos, chemical sources of current were the only method of obtaining electric energy. At that time there appeared the remarkable source of current, the Leclanche cell, the use of which has continued even in our times in various design and technical modification.

By the end of the 19th century, virtually all electrochemical couples were discovered suitable for practical use in electric cells and batteries. But far from all of the discovered electrochemical couples were then embodied in industrial models. For example, the mercury-zinc cells which were invented in 1884 and the silver-zinc batteries which were invented in 1898 began to be produced by industry only 50 years later.

The fuel cells which have come to be considered modern sources of current were invented as far back as 1839 by Grove and improved in 1880 by

Yablochkov. However, their practical realization in industrial models was impeded as a consequence of a number of design and technical difficulties, although fuel cells are very prospective sources of current.

The industrial production of electric power by thermal and hydroelectric plants which commenced at the end of the last century to some degree impeded the development of autonomous power sources.

Up to World War II, industry produced a rather limited range of voltaic cells and just three types of storage batteries. At the same time, some work was done directed at improving the operational performance of the sources of current and bettering their production methods, but technology did not achieve a sharp rise in the electrical operational performance of the cells or storage batteries.

With the beginning of World War II, there was a significant rise in the production of sources of current. The output of manganese-zinc cells and batteries in the U.S. during the war years was several score million units per day.

The appearance of new types of radioelectronic weapons caused the growth of new developments and search in the area of semiconductor and chemical sources of current. During these years, industrial models were developed and mass output commenced for such sources of current as mercury-zinc cells, silver-zinc storage batteries, and so forth.

Outstanding successes in the research, development and industrial manufacturing of autonomous sources of current were achieved during the postwar period with the appearance and development of missile and space technology and the rapid development of transistorized military and domestic radioengineering equipment which, in turn, required the development of small-sized sources of current with high specific performance.

During this period there was a sharp increase in the production of such chemical sources of current as the mercury-zinc and manganese-zinc miniature cells and batteries, the small-size circular and cylindrical cadmium-nickel sealed storage batteries, lamelless design storage batteries with cermet electrodes and silver-zinc storage batteries.

Sealed silver-cadmium storage batteries and nickel-zinc storage batteries also appeared. Cells with a solid electrolyte were developed designed for protracted storage, as well as cells and batteries for operating at a temperature of -50° centigrade. At the same time, semiconductor sources of current were developed.

The development of semiconductor generators from partisan mess kits used for powering radio sets by our partisans during the Great Patriotic War was moved far ahead by the efforts of Soviet physicists.

Photoelectric sources of current, solar batteries, are also widely used in space technology. Plasma thermion converters and magnetohydrodynamic generators are also being successfully developed. Here particular

attention is being paid to working out the methods of the direct conversion of various types of energy into electrical energy with maximum efficiency.

With the development and mastery of methods for the direct conversion of solar energy and the energy of the atomic nucleus into electrical energy there will be a substantial change in the ratio between the use of these types of energy and the energy of fossil fuels (coal, oil and gas). This ratio at present is 1 percent and 85 percent respectively (14 percent of the power resources are made up of wood and agricultural waste products).

Recently, the attention of engineers and scientists has been drawn to the problem of creating an electric car, the advantages of which over the motor vehicle in terms of the absence of highly toxic exhaust and noiselessness are obvious. However, the solution to this problem is determined by the development level of the sources of current, primarily chemical ones, since the modern gasoline engine makes it possible to derive around 500 watts of energy from a kilogram of its weight, while an acid storage battery produces around 50 watts, not counting the weight of the electric motor. In the opinion of scientists, the use of new sources of current for powering the electric car such as fuel cells or sulphur-sodium storage batteries will make it possible to successfully solve this problem which has become very urgent in cities with a large population.

In military equipment, autonomous sources of current hold a special place. Even in the last century, voltaic batteries were used in mine and torpedo weapons and in sapper equipment for detonating land mines, as well as in military telegraph, signaling and radio traffic. At present, the sphere of use of autonomous sources of current in military equipment is exceptionally large. The use of new more advanced sources of current in a number of instances will make it possible to substantially reduce the size and weight of the weapons or increase their combat life.

The purpose of the book is to familiarize a broad range of military and civilian specialists with modern sources of current.

The book gives a brief description of the operating principles of sources of current, and provides the electrical and operational characteristics of sources of current produced by our industry as well as the methods for operating sources of current providing for their trouble-free work over their life. Chargers have been described for charging various storage batteries and voltaic cells, the methods of eliminating malfunctions and repairs possible under the conditions of troop repair bodies.

Chapter One

BASIC CHARACTERISTICS OF SOURCES OF CURRENT

The characteristics of sources of current can be divided into electrical and operational. Among the first are the electromotive force, voltage, capacitance, internal resistance and energy efficiency, self-discharge and the specific capacitance and energy characteristics. The latter include the service life, the shelf life, the ability to work under conditions of vibration and shock stresses, and the ability to work under various climatic conditions, particularly in a broad temperature range.

For the semiconductor sources of current, a majority of the above-listed electrical characteristics do not apply, since the semiconductor sources operate from external sources of energy such as light, heat, and so forth, where the efficiency is the basic criterion. But such characteristics as voltage and internal resistance are also very important for the semiconductor sources.

Electromotive Force

The electromotive force (emf) of a source of current is the difference of the potentials of a nonworking source of current, that is, a source of current to which a consumer has not been connected.

For the chemical sources of current, the emf is determined by the difference of potentials of the positive and negative electrodes:

$$E = \varphi_a - \varphi_c, \text{ v.}$$

where φ_a -- anode potential, φ_c -- cathode potential.

The electromotive force of semiconductor sources of current is determined by a number of physical factors. For the thermoelements, it is determined by the coefficient of electromotive force for the semiconductor couples. This depends on the choice of the semiconductor substance. For the photo cells, it is determined by the type of photo cell and the temperature, while for a piezoelectric cell, by the material and pressure, and so forth.

The electromotive force of certain sources of current is given in Table 1.

Table 1

Emf of Chemical, Semiconductor Sources of Current

Name of Source of Current	Amount of emf, v
Lead-cadmium voltaic cells	2.40
Chlorine voltaic cell	2.05
Manganese-magnesium cell	2.00
Manganese-zinc cell, salt	1.80
Manganese-zinc cell, alkaline	1.50
Mercury-zinc cell	1.35
Air-zinc cell VD	1.40
Air-iron cell VDZh	1.00
Copper-zinc cell	0.96
Lead-acid storage battery	2.10
Silver-zinc storage battery	1.84
Nickel-zinc storage battery	1.83
Silver-cadmium storage battery	1.50
Iron-nickel storage battery	1.40
Cadmium-nickel storage battery	1.36
Fuel cells	1.00-1.20
Biological cells	0.60-1.00
Thermoelements	0.13-0.20
Plasma generators	0.70-2.50
Silicon photo element	0.55
Organic-matter photo cells	1.10

The electromotive force of a battery made up of series-connected sources of current of the same type equals the product of the emf of one cell by the number of these cells.

With the parallel connection of individual cells, the emf of the battery remains unchanged.

The international Clark and Weston cells are used as the standards of electromotive force. In conventional laboratory practices, it is possible to employ industrial models of standard voltage sources such as a mercury-zinc battery of the 3(R-04)-1 type, consisting of three R-04 cells.

An accurate measurement of the emf is carried out by the compensation method. An approximate measurement of the emf with an accuracy sufficient for practical purposes is made by a tube voltmeter or a voltmeter the input impedance of which is not lower than 1000 ohm per volt.

Voltage

The voltage of the source of current is measured with the external circuit closed to the load. One-shot current sources and semiconductor sources have an operating voltage which is always lower than the emf.

Chemical current sources, in the process of discharge, change their voltage from higher to lower. For the semiconductor sources, under the condition of the constancy of factors causing the appearance of the emf in them, the amount of the voltage remains fixed with an unvaried load.

In contrast to the one-shot sources of current, electric storage batteries, in addition to a discharge voltage which is less than the emf, have a charge voltage which exceeds the emf.

Generally speaking, the discharge voltage of a source of current is determined by the expression:

$$U_d = E - IR_{in}$$

In chemical sources of current, the internal resistance R_{in} of which changes in the charging process due to the occurrence of the emf of polarization, the amount of voltage can be determined from the equation:

$$U = E - E_p - IR_{in} = IR_l$$

where E -- the emf of the current source, E_p -- the emf of polarization, R_{in} -- the internal resistance of the current source, I -- the discharge current, R_l -- the load resistance in the external circuit.

The occurrence of the emf of polarization with discharging is explained by the fact that the rate of the electrode processes depends upon a number of factors such as temperature, the state of the electrolyte, the quality of the active substances and their state, and so forth. As a consequence of this, the electrode potentials of the electrochemical couple fall and the chemical source of current will possess a lower discharge voltage. The emf of polarization impedes the development of chemical sources of current in which the voltage would equal the difference of the electrode potentials of its electrochemical couple.

The basic factors which determine the voltage of the source of current are the internal resistance and the force of the discharge current. From the formula for the voltage, it follows that the lower the internal resistance, the greater the voltage. This same dependency is also valid for the discharge current. With an internal resistance equal to zero, the voltage of the source of current equals its emf.

The discharge of a chemical source of current is characterized by the initial, average and end voltage.

The initial voltage is less than the emf by the amount of the IR_{in} . With low temperatures, the initial voltage is less than with a positive temperature, as a consequence of a reduction in the mobility of the electrolyte ions.

The amount of average voltage is used in determining the charge or discharge energy of a source of current. The average voltage is determined from the discharge curves.

The end voltage characterizes the state of the source of current, and its capabilities for supplying energy to the external circuit. The amount of the end voltage ordinarily is set proceeding from the operating load conditions, that is, from the possible fall of voltage between the beginning and end of the discharge.

Table 2 gives data on the average voltage of certain chemical sources of current.

Table 2

Voltage of Chemical Sources of Current

Name of Sources of Current	Average voltage, v
Lead-cadmium cell	2.1-1.8
Chlorine cell	1.9-1.6
Manganese-magnesium cell	1.5-1.4
Manganese-zinc cell, alkaline	1.3-1.1
Manganese-zinc cell, salt	1.46-0.95
Mercury-zinc cell	1.25-1.1
Air-zinc cell VD	1.25-1.0
Copper-zinc cell	0.7-0.5
Silver-zinc storage battery	1.5-1.4
Silver-cadmium storage battery	1.15-1.05
Cadmium-nickel storage battery	1.2-1.1

The end voltage of the chemical sources of current, as was already stated above, is determined by the consumer, proceeding from the operating requirements of the equipment. But all sources possess a voltage at the end of discharging when their operation becomes virtually impossible due to the extremely rapid fall of the discharge characteristics.

Such a voltage for the acid storage batteries is an end voltage of 1.7 volts with long discharges and 1.5 volts with short ones. At a temperature of -20° , the end voltage of the same storage batteries equals one volt.

The end discharge voltage of the cadmium-nickel storage batteries, including the lamelless and sealed ones, at a normal temperature, is 0.9 volts, and at a temperature below zero, 0.7 volts.

The silver-zinc storage batteries, at a normal temperature, produced energy with a discharge down to 1.3 volts, and with a negative temperature, down to 0.9 volts.

The end voltage for the primary sources of current, with the exception of the mercury-zinc cells, is difficult to fix, since the discharge characteristics for a majority of the voltaic cells do not have steep areas, like the storage batteries, and as a consequence of this the amount of the end voltage

should be set proceeding from the requirements of the consumer.

Internal Resistance

The internal resistance of the source of current is a very important characteristic for the consumer, since it determines the operating system of the source of current. With a low internal resistance, the voltage drop in the source itself is small, and as a consequence of this, this source can take a significant load.

A source of current which possesses a high internal resistance is not capable of producing a heavy current for the external circuit over a short interval of time.

For the chemical sources of current, the internal resistance is determined by the direct-current resistance of the electrodes and electrolyte, as well as by the polarization resistance arising with a change in the electrode potentials during discharging.

If the polarization resistance is included in the total direct current resistance of the chemical source of current, then the voltage of this source can be expressed by the equality:

$$U_d = E - R_{in} I_d \text{ -- for discharge; } U_c = E + I_c R_{in} \text{ -- for charging.}$$

Hence the amount of internal resistance with an accuracy acceptable for practical calculations will be:

$$R_{in} = \frac{E - U_d}{I_d} \text{ for discharge; } R_{in} = \frac{U_c - E}{I_c} \text{ for charging}$$

The internal resistance of voltaic cells changes during the process of storage and use. The longer the cell is stored, the higher its internal resistance. In the process of discharging a voltaic cell, its internal resistance increases.

Generally speaking, the internal resistance of voltaic cells is determined by the electrochemical couple and by the dimensions of the cells. The large-capacity cells have a direct current resistance on the order of tenths of an ohm, while small low-capacity cells possess a resistance running into scores of ohms.

The lamel cadmium nickel and iron-nickel storage batteries, in the process of discharging, change their direct current resistance. While at the beginning of the discharge and up to a loss of 50 percent of the capacitance, the resistance of the storage batteries changes insignificantly, by the end of the discharge, it increases by double.

The approximate value of the internal resistance of the cadmium-nickel and iron-nickel storage batteries can be obtained from the formula:

$$R_{in} = \frac{0.35}{Q}$$

where Q -- the capacitance of the storage battery in amphours at a normal temperature.

For the semiconductor sources of current, the internal resistance is determined by the character of the substance. The resistance of the silicon solar cells is within the limits of from 500 to 1000 ohms, and depends upon the type and size of the cell. The internal resistance of atomic batteries, depending upon the semiconductor substance and the source of bombardment varies within limits of from 100 to 10^{12} ohms. On the other hand, the internal resistance of the thermoelements is thousandths of an ohm.

As is the case with the chemical sources of current, the internal resistance of semiconductor cells determines their operating conditions for the external load. The thermoelectric batteries which possess a low internal resistance are capable of supplying a significant current to the external circuits, but the current during the operation of atomic batteries is only 10^{-15} amps.

Capacitance

The concept of "capacitance" is characteristic only for the chemical sources of current, since in the semiconductor cells, with the exception of atomic batteries, the operating time is determined by the length of the action of external factors such as heat, light, pressure, and so forth.

Generally speaking, that quantity of electric energy which can be stored or delivered by the source of current is called the capacitance of the chemical source of current.

For the voltaic cells, there is a discharge capacitance determined by the quantity of electricity which the cell can produce in discharging down to the end voltage.

For the storage batteries, in addition to the discharge capacitance, there are also characteristics for charge capacitance which numerically equals the quantity of electricity stored by the battery in charging. Thus, capacitance:

$$Q = It, \text{ amps} \cdot \text{hours}$$

where I -- intensity of charge or discharge current in amps, t -- time of charging or discharging in hours.

The designated formula is valid for instances when the current has not altered in the process of charging or discharging. With the discharging of the source of current to the permanent resistance which is most frequently encountered in practice, for determining the capacitance, the average value

of the discharge current, I_{av} , is used. This equals the arithmetical average (approximately) of the currents of the beginning and end of discharging. Hence, capacitance:

$$Q = I_{av} t, \text{ amps} \cdot \text{hours}.$$

The capacitance of any chemical source of current depends upon the amount of the discharge current and the temperature. In the tables for the performance of sources of current, along with the capacitance, either the current at which the given capacitance is obtained is given or the amount of the load resistance. Ordinarily the latter is given for the performance of voltaic cells, the capacitance of which (manganese-zinc, air-zinc, and air-iron) can be determined tentatively from the equality:

$$Q = \frac{U_i + 2U_e}{3R} \cdot t, \text{ amps} \cdot \text{hours}$$

where U_i and U_e -- the initial and end voltage in volts, R -- the load resistance in ohms, and t -- the discharge time in hours.

In selecting the source of current, it is essential to note the graphs showing the dependency of capacitance upon discharge current. From these graphs it is possible to judge the possibility of using the given source of current in the required discharge conditions.

The capacitance data given in the tables ordinarily apply to the rated or guaranteed capacitance which the source of current should supply, if its discharging has been carried out under conditions indicated by the manufacturing plant. Such capacitance is the minimum possible.

As for the actual capacitance, ordinarily it exceeds the rated capacitance by 15-20 percent. This is explained by the need for the manufacturing plant to maintain a certain production reserve.

The capacitance of storage batteries discharged to a fixed resistance can be determined from the approximate formula:

$$Q = \frac{U_{av}}{R} \cdot t = \frac{U_i + U_e}{2R} \cdot t, \text{ amp-hours}$$

where U_i and U_e -- the voltage at the beginning and end of discharge, R -- resistance, t -- discharge time.

The capacitance of the sources of current depends upon the quantity of active materials included in them. This is determined by the dimensions of the source of current.

The influence of the discharge conditions on the capacitance produced by the chemical source of current is shown in Figure 1 where the performance of certain cells and batteries is shown. With an increase in the discharge current, the capacitance of the majority of the chemical current sources declines.

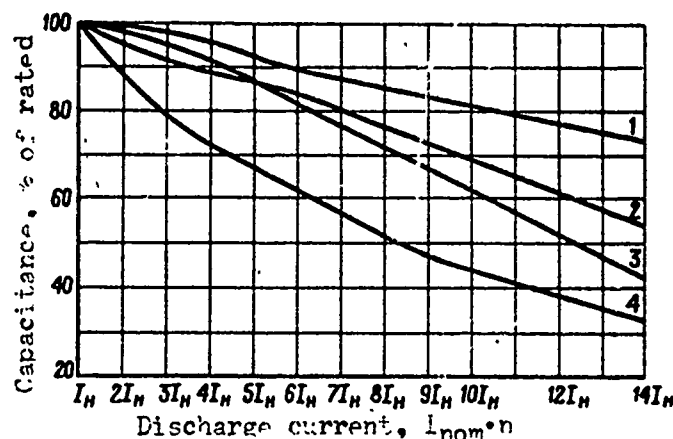


Figure 1. The influence of discharge conditions on the capacitance produced by chemical current sources:

- 1 -- silver-zinc storage batteries; 2 -- silver-cadmium storage batteries; 3 -- cadmium-nickel lamelless storage batteries; 4 -- manganese-zinc cells.

Temperature influences capacitance particularly strongly. The upper operating limit for a majority of the sources of current is a temperature of $+50^{\circ}$. The chemical sources of current possess a negative temperature coefficient. With a rise in the temperature from zero degrees to the upper limits, the capacitance, with the discharging of the sources of current, increases, but in discharging from zero toward the negative temperatures, it decreases. This is explained by a change in the rate of the electrochemical reactions.

With a rise in the temperature above the normal ($+18^{\circ} - +20^{\circ}$), the capacitance of alkaline storage batteries increases by 0.5 percent for each degree of temperature.

With low temperatures, the capacitance of the chemical sources of current sharply declines. Here the voltage of the current source also falls. For a majority of the voltaic cells, discharging at a temperature of below -20° is possible only with a low discharge current. Certain voltaic cells, for example, the mercury-zinc cells, at a temperature below zero are virtually inoperable, with the exception of special cold-proof cells such as the RTs83kh and RTs85kh.

The capacitance efficiency of the storage batteries at low temperatures also declines sharply. At a temperature of -40° , the lamel cadmium-nickel batteries are capable of producing only 20 percent of their

rated capacitance, while the iron-nickel storage batteries at this temperature are virtually inoperable.

Of all the types of storage batteries, the lamelless cadmium-nickel storage batteries have proven to be the most stable in operating at a temperature below zero. The lower temperature limit for these batteries equals -50° .

Certain storage batteries, for example, the silver-nickel ones, can operate at negative temperatures (-30° and lower) after brief operation under short circuit conditions for the purpose of warming.

Figure 2 gives the characteristics for the capacitance dependency of certain sources of current upon temperature.

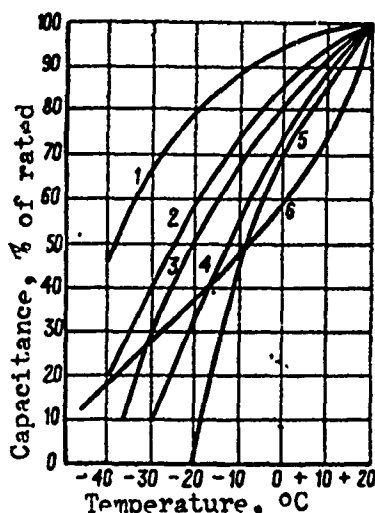


Figure 2. Characteristics of the capacitance dependency of certain chemical sources of current upon temperature:

- 1 -- cadmium-nickel lamelless storage batteries;
- 2 -- silver-zinc storage batteries;
- 3 -- cadmium-nickel lamel storage batteries;
- 4 -- cadmium-nickel sealed storage batteries;
- 5 -- mercury-zinc cells;
- 6 -- manganese-zinc voltaic cells.

The capacitance produced with the discharging of the base cadmium-nickel, iron-nickel and cadmium-nickel lamelless storage batteries to a significant degree depends upon the density of the electrolyte. This is

In charging the storage batteries, the amount of the charge capacitance is influenced both by the charging conditions and the temperature. The influence of the charging conditions on capacitance is expressed in the fact that in charging with a heavy current, the storage battery is not able to gain the required charge capacitance, since the electrochemical reactions occurring during this require a definite time for completion. A storage battery which has not been adapted for charging under rush conditions is not able to gain the required capacitance, and for this reason, in discharging, produces a reduced discharge capacitance.

In charging under low temperature conditions, when the rate of the electrochemical reactions declines, the storage battery also is not able to obtain the required charge capacitance.

In charging under conditions of an increased temperature, certain types of storage batteries, for example, the iron-nickel ones, as a consequence of the large self-discharge, also do not produce the proper capacitance.

particularly felt under low temperature conditions.

Specific Characteristics

The specific characteristics of the chemical sources of current such as specific capacitance, specific energy and specific power, are the most indicative from the standpoint of a possibility of comparing current sources which differ in terms of their electrical characteristics and the possibility of their use under rapid discharge conditions.

The specific capacitance is the ratio of the actual discharge capacitance of the current source to its volume or weight. The specific capacitance for volume Q_v and for weight Q_q is determined from the expressions:

$$Q_v = \frac{Q}{V}, \frac{\text{a-hr}}{\text{dm}^3},$$

$$Q_q = \frac{Q}{q}, \frac{\text{a-hr}}{\text{kg}},$$

where Q -- capacitance, V -- volume, q -- weight of source.

The specific capacitance makes it possible to compare the sources of current, the voltages of which are the same. As a consequence of this for comparing sources which differ in voltage, it is essential to use the characteristics for the specific power or specific energy:

$$P_v = \frac{IU}{V}, \frac{\text{wt}}{\text{dm}^3} \text{ -- specific volume power;}$$

$$P_q = \frac{IU}{q}, \frac{\text{wt}}{\text{kg}} \text{ -- specific weight power;}$$

$$W_v = \frac{IU}{V} \cdot t, \frac{\text{w-hr}}{\text{dm}^3} \text{ -- specific volume energy;}$$

$$W_q = \frac{IU}{q} \cdot t, \frac{\text{w-hr}}{\text{kg}} \text{ -- specific weight energy.}$$

The full power of the current source is determined by the equality:

$$P_{\text{full}} = IE = I (IR + IR_{\text{in}}) = I^2 R + I^2 R_{\text{in}},$$

where $I^2 R$ designates the power consumed by the external circuit, and $I^2 R_{\text{in}}$ -- the internal circuit.

The power required by the internal circuit is stray, and for this reason the useful power can be expressed by the equality:

$$P_{\text{use}} = P_{\text{full}} - I^2 R_{\text{in}} = I^2 R.$$

The maximum power can be obtained from the current source in meeting the condition $R = R_{in}$, that is, when the resistance of the external circuit equals the internal resistance of the power source. This power equals:

$$P = 2I^2R.$$

The maximum current can be obtained under the condition of $P_{use} = 0$, that is, when the current source is short circuited:

$$IE - I^2R_{in} = 0, \text{ that is, } IE = I^2R_{in}, I = \frac{E}{R_{in}}$$

From the last expression it follows that the amount of current with a short circuit is determined by the internal resistance of the current source.

Table 3 gives the characteristics of certain chemical current sources in terms of the specific capacitance and specific energy. The data given in the table apply to normal conditions in terms of current and amount of voltage. Naturally, with a deviation in the conditions for using one or another current source from the manufacturer recommended, the characteristics will have another value.

Efficiency

The efficiency of a chemical current source is the name given to the ratio of the energy consumed by the current source to the energy stored by the active masses of its electrodes for the one-shot cells, or the ratio of the capacitance produced in discharging to the capacitance obtained in charging for the storage batteries.

For the semiconductor current sources, the efficiency is the ratio of the energy consumed on useful work to the energy providing the operation of the semiconductor current source (thermal, light, atomic and so forth), that is, the efficiency.

The efficiency of semiconductor current sources is low: 8-10 percent for the thermoelements, 0.1-11 percent for the photo cells and 0.1-2.5 percent for the atomic batteries.

In the press it has already been pointed out that they expect to obtain the highest efficiency from the plasma, hydrodynamic and fuel sources of current which, according to the calculations and laboratory experiments, can reach almost 100 percent of energy use.

For storage batteries, three types of efficiency are distinguished: capacitance efficiency η_Q , the energy efficiency η_W and the voltage efficiency η_V .

Table 3

Specific Capacitance and Specific Energy of Chemical Sources of Current

Name of current source	specific capacitance		specific energy	
	volume $\frac{a-hr}{dm^3}$	weight $\frac{a-hr}{kg}$	volume $\frac{w-hr}{dm^3}$	weight $\frac{w-hr}{kg}$

Voltaic Cells

FMTs Manganese-zinc cell	19	11	25	15
326 Manganese-zinc cell	100	40	120	50
MTs Manganese-zinc cell	90	27	124	40
KES Manganese-zinc cell.....	5.1	3.1	30	17
Frame-type manganese-zinc cell	53	24	213	96
GB-u-10-1.3 pancake cell	8.7	5.6	86	50
Krona-1L pancake cell	12.5	7.1	112	64
Krona VTs pancake cell	30	15	270	135
Finish Manganese-zinc cell	29	16	235	133
Manganese-magnesium cell	130	64	200	97
Copper oxide cell	53	80	35	52
RTs83kh mercury-zinc cell	226	53	282	67
Chlorine-lead cell	70	27	127	46
Copper-magnesium cell	70	33	83	40
Silver-zinc cell	130	50	200	70

Storage batteries

Lead acid (aviation)	39	16	58	26
KN cadmium-nickel lamel	36	13	43	16
ZhN iron-nickel lamel	30	15	43	15
KNB cadmium-nickel lamelless	54	32	65	36
D-0.25 cadmium-nickel sealed	62	14	75	17
TsNK cadmium-nickel sealed	63	21	76	26
KNB cadmium-nickel sealed	42	15	52	18
STs25 silver-zinc	87	77	130	114
Silver-cadmium	100	53	105	56
Nickel-zinc	67	36	106	57

$$\eta_Q = \frac{Q_d}{Q_c} \cdot 100 = \frac{I_d t_d}{I_c t_c} \cdot 100\%$$

$$\eta_W = \frac{W_d}{W_c} \cdot 100 = \frac{I_d U_d t_d}{I_c U_c t_c} \cdot 100\%$$

$$\eta_U = \frac{U_d}{U_c} = \frac{I_d U_d t_d}{I_c U_c t_c} = \frac{U_d}{U_c} \cdot 100\%$$

Table 4 gives the efficiency characteristics for certain storage cells.

Storage Battery Efficiency

Table 4

Type of Storage Battery	Efficiency in percent	
	Capacitance	Energy
Lead acid aviation	70-80	65-70
Cadmium-nickel lamel KN	58-67	44-50
Cadmium-nickel lamelless KNB	53-75	45-50
Cadmium-nickel sealed circular	55-65	45-50
Cadmium-nickel sealed cylindrical	50-67	48-55
Iron-nickel lamel ZhN	47-58	41-47
Silver-zinc	90-98	80-85

Self-discharge

The self-discharge of a chemical current source is the name given to its loss of capacitance in the storage process, when the current source has no load. The self-discharge arises as a consequence of the interaction of the active masses and the electrolyte. The loss of capacitance by the chemical current sources puts a restriction on the length of their storage and operation. For this reason, the requirement of minimal self-discharge of the current sources is completely valid.

The daily self-discharge is determined from the expression:

$$\delta = \frac{Q_1 - Q_{st}}{Q_1 \cdot n} \cdot 100 \text{ percent,}$$

where Q_1 -- the initial capacitance of the current source, Q_{st} -- the capacitance after storage, n -- the number of days of storage.

For the voltaic cells, there is the concept of shelf life which, in essence, is the rate of self-discharge. In voltaic cells with an electrochemical manganese-zinc system, self-discharge occurs as a consequence of

the dissolving of the zinc in the electrolyte and a reduction of the capacitance of the manganese electrode due to its loss of active oxygen. Self-discharge in the cadmium-nickel storage batteries is explained by the gradual loss of oxygen by the positive electrode and the oxidation of the negative electrode in the storage process.

The self-discharge of chemical current sources can occur also with a violation of the storage and operating rules for the cells and batteries, when chemical current sources are stored in an area with acid or base fumes, in a humid atmosphere, when bridges from current-conducting particles form between the leads, and so forth. However, these losses are not included in the amount of self-discharge indicated in the manufacturing specifications of the current source as it is caused only by the chemical processes occurring within the current source.

For the purpose of reducing self-discharge, voltaic cells and batteries should be stored at a temperature of around -5° .

The self-discharge characteristics of certain current sources are given in Table 5.

Service Life and Shelf Life

The service life and shelf life of current sources are very important characteristics, since they determine the possibility of operating a given piece of equipment over a certain period of time, that is, operating life. The use of current sources with a short service life and a short shelf life forces the consumer to create reserves under the condition of their constant replacement. These characteristics are particularly important for field equipment operating away from supply and repair facilities.

The primary current sources -- the voltaic cells -- are characterized by shelf life, that is, by the time during which the voltaic cells or battery loses not more than 30 percent of its initial capacitance. Here, for the voltaic cells of the hydroelectric type or those filled with an electrolight in operating them, there is also the characteristics for the shelf life in a filled state.

The secondary current sources -- the storage batteries -- are characterized by a service life calculated by the number of charge-discharge cycles which the storage battery can endure without a marked decline in the discharge capacitance.

The other characteristic storage batteries -- the shelf life -- determines the ability to operate at the end of a certain period of storage in a dry state or filled with the electrolyte. Some of the storage batteries require a protracted time for preparing to operate, and as a consequence of this, the consumer is forced to keep them filled with the electrolyte. For such current sources, the characteristics for the shelf life in a filled state are decisive.

Table 5

Self-discharge of Current Sources			
Type of Current Source	Self-discharge in percent of rated capacitance		
	Storage temperature		
	+40°	+20°	below zero
Manganese-zinc cells	--	25-30% in 4-12 mos. of storage	10% in 3 yrs. at -30°
Mercury-zinc cells	--	Around 10% during yr. of storage.	--
Lead acid storage battery	--	Around 30% per month	--
Iron-nickel storage battery ZhN	100% in month	18-30% in mo.	7% in mo. at -10°
Cadmium-nickel storage battery KN	24% in mo.	11-18% in mo.	Around 0% at -10°
Cadmium-nickel lamelless KNB	20-22% in month	15% in mo.	Around 0% at -10°
Cadmium-nickel sealed circular	40% in mo.	35% in mo.	--
Cadmium-nickel sealed cylindrical	30% in mo.	20% in mo.	--
Cadmium-nickel sealed KNG	--	20-25% in mo.	--
Silver-zinc	40-45% in month	5-15% in mo.	--
Silver-cadmium	--	10% in 6 mos.	--
Nickel-zinc	--	18-25% in mo.	--

As a rule, the semiconductor current sources have a long service life.

The service life and the shelf life of certain current sources are given in Table 6.

Resistance to Impact and Vibration Loads

A predominant number of current sources used to power worn or carried equipment or aircraft equipment is subject to the effect of impact loads and vibration. The only exception is the hydroelectric voltaic cells and storage batteries designed for powering stationary units.

Table 6
Service Life of Chemical Sources of Current

1) Наименование источника тока	Начальные значения 2)		В конце срока 3) сохранности		4) Срок службы, челл	5) Срок сохранности	
	напряже- ние, в	емкость, а·ч	напряже- ние, в	емкость, а·ч		в сухом	в масле
Cells and batteries							
RTs cell No 286	1.5	ок. 0.2 approx.	—	ок. 0.17	—	3 мес.	—
RTs cell No 316	1.5	ок. 0.45	—	ок. 0.35	—	6 мес.	—
RTs cell No 343	1.5	ок. 1.20	—	ок. 0.90	—	12 мес.	—
RTs cell 1.6-FMTs-u-3.2 ...	1.6	3.2	1.32	2.6	—	12 мес.	—
RTs cell KRS-1-0.5	3.7	0.5	3.30	0.27	—	6 мес.	—
Krona-L RTs cell	9.0	0.15	—	0.10	—	6 мес.	—
Krona VTs VTs cell	9.0	0.60	—	0.45	—	9 мес.	—
RTs cell Finish	9.0	ок. 1.0	—	—	25 cycles capac. 0.1 а- hr.	—	—
RTs cell 70-AMTsG-u-1.3 ...	70	1.3	55	1.05	—	15 мес.	—
Mercury-zinc cell RTs11 ...	1.25	0.02	—	—	—	6 мес.	—
Mercury-zinc cell FTS53 ...	1.25	0.20	—	—	—	12 мес.	—

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Key:

1. Name of current source
2. Initial values
3. At end of shelf life
4. Service life, cycles
5. Shelf life
6. voltage, volts
7. Capacitance, amp-hours
8. Dry
9. Filled

Table 6 (cont.)

1) Наименование источника тока	Начальные значения		3) сохранность		4) Срок службы, дата	5) Срок сохранности	
	напряже- ние, в	емкость, 7) в-ч	напряже- ние, в	емкость, 7) в-ч		в сутки	в месяцы
Mercury-zinc cell KTs63 ...	1.25	1.20	—	—	—	30 мес.	—
Copper oxide cell	0.65	—	0.65	—	—	10 yr.	—
Copper chloride mag. cell .	1.50	—	—	—	—	unlim.	10 hr.
Lead-zinc cell	2.20	—	—	—	—	24 мес.	2-3hr.
Storage batteries							
Lead acid	—	—	—	—	75-100	5 yr.	1 yr.
Cadmium-nickel KN	—	—	—	—	750-1000	7 yr.	2 yr.
KN sealed circular	—	—	—	—	50-150	To 2 yr.	—
KN sealed cylindrical	—	—	—	—	100-200	To 2 yr.	—
KN sealed KNG	—	—	—	—	600	Over 2 yr.	—
Cadmium-nickel KNE	—	—	—	—	200-300	7 yr.	2 yr.
Silver-zinc	—	—	—	—	10-100	3 yr.	6-9 mo
Silver-cadmium	—	—	—	—	Over. 100	3 yr.	2 yr.
Nickel-zinc	—	—	—	—	50-100	3 yr.	6-12 Mo.

In terms of resistance to the effect of impact load and vibration, a majority of the dry voltaic cells satisfy the requirements made on the equipment which they are designed to power. These cells and batteries can withstand the effect of both one-shot and repeated impact loads with an acceleration to 25 g as well as vibrations with a frequency of from 10 to 10,000 hertz with an acceleration up to 10 g. The manganese-zinc and mercury-zinc cells are particularly resistant to the effect of shocks and vibrations, and they can withstand the effect of impact loads with an acceleration of up to 400 g.

The resistance to vibration and shocks of the storage batteries depends upon the position in which the storage battery is with the effect of the stress on it. For storage batteries with a loose plate assembly, for example, the cadmium-nickel lamel and lamelless storage batteries, the iron-nickel and particularly the acid batteries, the most dangerous is vibration and shaking in a vertical direction which causes fractures in the current bars and the appearance of cracks in the plastic tops of the vessels.

For storage batteries of the KNB [cadmium-nickel lamelless] type, an acceleration of 25 g is the tolerable impact load in a vertical direction. With the effect of an impact load in a horizontal direction, the KNB batteries can tolerate shocks with an acceleration to 120 g.

The silver-zinc and silver-cadmium storage batteries which have a fixed assembly of electrode packs can withstand jars and shocks with an acceleration of over 10 g, in a vertical direction and more than 100 g. in a horizontal direction. The silver-zinc and silver-cadmium low capacitance storage batteries are particularly resistant to the effect of blows and vibration.

The resistance to vibration and shocks of the sealed storage batteries, both circular and cylindrical, is rather high. They withstand the effect of an impact load in all directions with an acceleration up to 100 g. and a vibration load to 2000 hertz with an acceleration of 10 g. The large-sized storage batteries of the KNG [cadmium-nickel sealed] type are also noted for the same resistance. They can withstand an impact load with an acceleration up to 400 g.

The sealed batteries of all types perform well under conditions of both an increased and reduced pressure, and can be carried by any types of transport.

The resistance of semiconductor current sources to vibration and shocks is determined basically by the design parameters and the purpose. As is known, the solar batteries used in space equipment withstand accelerations on the order of several hundred g.

Table 7

Temperature Characteristics of Current Sources

Name of Current Source	Operating limit at temperature below zero, de- grees	Capacitance at given tempera- ture in percent of capacitance at +20°C
------------------------	---	---

Voltaic Cells

MTs [manganese-zinc] cell 1.6-FMTs-u-3.2 (Saturn)	-40	9.1
MTs cell No 373 (Mars)	-40	10
MTs battery KBS-kh-0.7	-20	29
MTs battery 70-AMTsG-u-1.3	-40	10
MTs Battery 70-AMTsG-1.3	-20	23
Mercury-zinc cell RTs63 in 5-hour discharge system	0	1
Mercury-zinc cell RTs83kh in 10-hour discharge system	-30	30
Chlorine-zinc cell	-40	80

Storage Batteries

Lead-acid	-30	10
Cadmium-nickel lamel KN	-40	17
Iron-nickel lamel ZhN	-20	65
Cadmium-nickel lamelless KNB	-40	60
Cadmium-nickel sealed circular	-30	25
Silver-zinc noninsulated	-30	to 50
Silver-zinc STs25 insulated with 3-mm layer of styrofoam	-40	20
Silver-cadmium noninsulated	-30	20
Silver-cadmium insulated	-40	25

The Operating Temperature Range

The demands made upon current sources in terms of temperature resistance derive from the operating conditions of the equipment which they power.

A predominant number of mobile equipment with autonomous power sources operates in the open air, where temperature fluctuations during the year can be from $+50^{\circ}$ to -50° . A range of from $+40^{\circ}$ to -40° ordinarily is accepted as a practical interval of temperature fluctuation which the current source should stand.

While the upper limit of the temperature range of $+40^{\circ}$ is met rather well by virtually all current sources, both the voltaic cells and the storage batteries, and the efficiency of chemical current sources rises at this temperature, under low temperature conditions and particularly at a temperature of -40° , it is hard to find any chemical current source the efficiency of which would be close to the rated at a normal temperature. Table 7 gives the performance of certain current sources at low temperatures.

The semiconductor current sources, at a temperature above zero, operate normally. At a reduced temperature, certain semiconductors reduce the current output for the external circuit as a consequence of an increase in their internal resistance. Other semiconductors, for example, the silicon photoconverters, with a drop in temperature increase the emf.

The atomic, plasma and fuel current sources virtually do not depend upon the surrounding temperature.

The Designating of Current Sources

The voltaic cells, the range of which is very broad, are named both by a symbol containing the electrical characteristics of the battery or the cell, as well as by a code in the form of a number or trade name.

The symbol of the voltaic cells ordinarily begins with a number indicating the voltage of the cell or the battery in volts such as 1.28, 1.5, 13, 109, and so forth.

The letters following the numbers indicate the area of use of the cell or battery (the first letter), and then follow letters designating the electrochemical couple or design, for example:

AMTs -- anode manganese-zinc (can).
AMTsG -- anode manganese-zinc pancake.
ANSEMs -- anode-filament-grid manganese-zinc.
NVMIs -- filament air (depolarizer) manganese-zinc.
ASMTsG -- anode-grid manganese-zinc pancake.
ANMTs -- anode-filament manganese-zinc.
NMTs -- filament manganese-zinc.

NMTsG -- filament manganese-zinc pancake.
 FMTs -- flashlight manganese-zinc.
 ANV -- anode-filament air.
 RZA -- radiosonde anode.
 RZN -- radiosonde filament.
 STMTs -- sound telephone manganese-zinc.
 PMTs -- instrument manganese-zinc.
 SNMTs -- sound filament manganese-zinc.
 SAMTsG -- sound anode manganese-zinc pancake.
 TMTs -- telephone manganese-zinc.
 TVNTs -- telephone air manganese-zinc pancake.
 VTs -- air-zinc.
 EVMTsG -- electronic flash manganese-zinc pancake.

If, after the letter symbol and a hyphen there is the small letter "u," this means that the cell or battery belongs to the universal type operating at a temperature of from -40° to $+50^{\circ}$; if there is the letter "kh," then this means it is "cold-proof." If there are no such letters or there is the letter "l," then these cells are of the summer type.

The figures following the letter symbol designate the capacitance in amp-hours, or, if the letter "ch" comes after the numbers, this is the number of operating hours.

The letter "p" coming after the numbers designates the design of the battery, the panel-type.

A large number of voltaic cells and batteries are designated by numbers. Among them are the cells 283, 286, 343, 374 and others, the output of which began recently.

Certain batteries have trade names such as "Pioneer," "Krona," "Sinichka," and "Finish."

For the mercury-zinc cells, the symbol indicates the electrochemical couple, for example, RTs and the number of the cells designating its size. If the letter "u" follows after the number, this cell is of the universal type operating in a range of from -30° to $+50^{\circ}$, and if there is the letter "t," then it is among the heat-proof cells operating from 0° to $+70^{\circ}$.

For the storage batteries, a somewhat different system of designation has been introduced, where the first figure or number designates the number of storage cells in the battery, then follows the electrochemical couple, and the last figures designate the capacitance in amp-hours. Such a system is effective for the cadmium-nickel and iron-nickel storage batteries and batteries as well as for the cadmium-nickel lamelless storage batteries. For the latter, after the designation of the electrochemical couple, there is the letter B for lamelless. This same system has been maintained for the silver-zinc, silver-cadmium and nickel-zinc storage batteries. For the silver-zinc storage batteries and batteries, after the designation of the electrochemical couple, STs [silver-zinc], there

is a letter indicating the discharge conditions: "K" for short, "S" for average, "D" for long, "N" for an average discharge system with a large number of cycles and "B" for a buffer system.

For the silver-cadmium storage batteries, in addition to the designation SK, there is the SKG type for sealed.

The sealed cadmium-nickel storage batteries are designated by one or several letters, after which follow figures indicating the amount of capacitance. The letter "D" in the designation of a storage battery designates circular, TsNK is a cylindrical cadmium-nickel battery and KNG a cadmium-nickel sealed one.

For the semiconductor sources of current, only the kerosene thermoelectric generators have the designation TEKK, where, after the abbreviated name, there is a figure showing the power in watts. The silicon photocells for the solar batteries have the designation FKD.

The atomic sources of current have the trade names of "Romashka" and so forth.

Chapter Two

CHEMICAL SOURCES OF CURRENT

Chemical sources of current is the name given to devices by which the energy of spatially separate oxidation-reduction reactions is converted into electric energy. The process of converting chemical energy into electrical in a chemical source of current is called discharging.

In terms of the type of operation, all known chemical sources of current are divided into two groups: voltaic cells or primary sources of current, and electric storage batteries or secondary sources of current.

In the primary chemical sources of current are the devices which permit a single use of the active materials found in them. Here, the delivery of electric power can be achieved in one or several drains. A completely discharged voltaic cell is not fit for further use.*

The voltaic cells, in turn, are divided into liquid electrolyte cells and dry cells the electrolyte of which is a nonflowing paste or saturated materials.

Secondary chemical sources of current or electric storage batteries are the name given to the chemical sources of current which can be reused after discharging by further charging, that is, by passing an electrical current through the storage battery in the opposite direction to the discharge current. The discharging of the storage battery is accompanied by a conversion of chemical energy into electrical, and the active substances, as a result of the chemical reaction, are converted into different substances called the discharge products. The charging of a storage battery, on the contrary, converts electrical energy into chemical, and the discharge products are turned into the initial active substances.

The work of a chemical current source can easily be understood from the example of examining the processes occurring in the simplest Jacobi-Daniell voltaic cell.

* At present, voltaic cells are produced the capacitance of which can be partially restored by repeated recharging, analogous to the storage batteries.

The Jacobi-Daniell cell consists of a copper electrode submerged in a solution of blue vitriol CuSO_4 , and a zinc electrode submerged in a solution of zinc vitriol ZnSO_4 , and the solutions come into contact with one another, but do not mix, since they are separated by a partition which is made from a porous material (Figure 3).

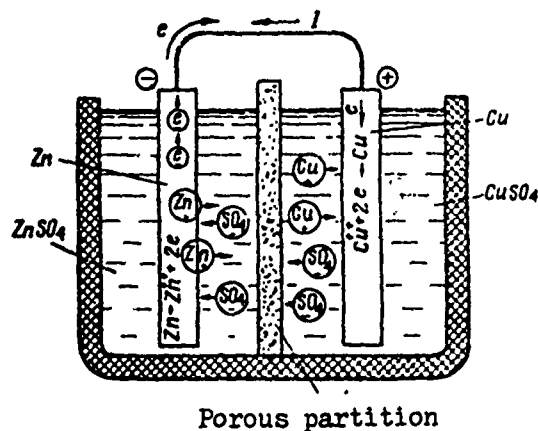
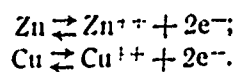
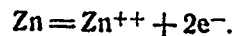


Figure 3. A Jacobi-Daniell cell

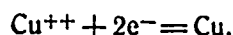
As long as the cell is disconnected, reactions cannot occur. Here, electrochemical equilibriums are established only on the surfaces of electrodes which are in contact with the solutions, that is, the zinc atoms and the electrons of the zinc electrode are in equilibrium with the zinc ions in the solutions, while the copper atoms with the electrons of the copper electrode are in equilibrium with the copper ions in the solution. These equilibriums can be written down in the form of the following electrochemical equations:



In closing the external circuit of the Jacobi-Daniell cell, the zinc electrode is oxidized. This means that on the surface of the zinc electrode which is in contact with the solution, the zinc atoms are converted into zinc ions and shift into the solution. The electrons liberated here move through the external circuit to the copper electrode. The aggregate of these processes is expressed by the electrochemical equation.

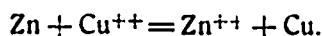


On the copper electrode, the copper ions are reduced. The electrons coming here from the zinc electrode join with the copper ions emerging from the solution. Copper atoms are formed which precipitate out on the electrode in the form of a metal:



Thus, with the connecting of the cell, a continuous oxidation-reduction reaction begins to occur in it. The electrons from the zinc electrode cross over the external circuit to the copper electrode, the electrochemical equilibria on the electrodes are upset and in the solution a directed movement of ions occurs.

An equation for the reaction occurring in a Jacobi-Daniell cell and written in the ion form is obtained by adding together the above-given equations for the electrodes:



Consequently, with the use of the cell, an oxidation-reduction reaction between the zinc atoms and the copper ions occurs in it. The electrode on which the oxidation occurs is called the anode, and the electrode on which the reduction occurs is the cathode.

Thus, the zinc electrode is the anode and the copper one is the cathode. Here, the anode is negatively charged (the electrons run from it into the external circuit), and the cathode is positively charged (the electrons move toward it), that is, the distribution of the charge signs of the electrodes in a voltaic cell is opposite to the one which occurs in electrolysis. The reason for this is that the processes occurring in a voltaic cell, with its use, are the reverse to the processes occurring with electrolysis. With the use of a voltaic cell, the chemical reaction which occurs spontaneously in it produces a current, while in electrolysis, the current delivered to the electrodes causes a chemical reaction.

The direction of the movement of the ions in the internal circuit of the voltaic cell (in the solution) is caused by the same electrochemical processes occurring around the electrodes. As was already stated, around the zinc electrode, the zinc ions escape into the solution, while around the copper electrode, the solution is constantly depleted of copper ions. As a result of this, an electric field is created in which the Cu^{++} and Zn^{++} ions in the solution move from the zinc electrode to the copper one, while the SO_4^{--} ions move in the reverse direction. As a result, the fluid both around the cathode and around the anode remains electrically neutral.

Thus, in line with the spatial separation of the oxidation and reduction processes in the course of the reaction, a directed transfer of ions and electrons occurs, while the movement of the electrons in the external circuit is an electric current the energy of which can be utilized.

In principle, any oxidation-production reaction can provide electric energy. However, in practical terms the number of oxidation-reduction reactions usable in chemical sources of current is not great. This is explained by the fact that not any oxidation-reduction reaction can be used for a cell which possesses technically valuable properties (an emf which is high and virtually constant in time, the possibility of discharging with a heavy current, the storability of the cell and so forth). Moreover, many oxidation-reduction reactions require the consumption of costly substances.

A. Voltaic, Fuel and Biological Cells

The voltaic cells are the most widely found sources of current as a consequence of their cheapness and operating simplicity. The range of voltaic cells and batteries is very broad both in terms of the electrochemical couples as well as in terms of the sizes of the cells and batteries.

The voltaic cells, in terms of the operating method, are divided into dry cells which do not require preparatory operations for use, and wet (reserve) cells which are filled with the electrolyte or water, depending upon the state of the electrolyte before use.

In terms of shape, the dry voltaic cells are divided into square, cylindrical and pancake. The wet cells are produced in vessels of rectangular shape.

Manganese-Zinc Dry Cells and Batteries

The most widely used are cells and batteries with a hydrochemical couple of zinc and manganese dioxide, or, as they are usually called, manganese-zinc (MTs) cells. Flashlights, radio receiver and transmitting equipment, telephones, signaling instruments, measuring equipment -- this is a far from complete list of uses for these extremely trouble-free, convenient-to-use and cheap current sources.

The electrochemical system of zinc and manganese dioxide has two modifications: one with a chloride (salt) electrolyte and the other with an alkaline one.

The manganese-zinc cells with a salt electrolyte developed around 100 years ago up to the present are the most widely found sources of current. In terms of design, the dry MTs cells are divided into can and pancake [button]. The arrangement of the MTs cells of the can and pancake type is shown in figures 4 and 5.

The positive electrode of a can-type cell is the manganese dioxide in a mixture with powdered graphite pressed on a carbon core which is the current drain. The zinc can is the negative electrode. In the can-type cells, the electrolyte consists of ammonium chloride and zinc chloride thickened with starch and flour.

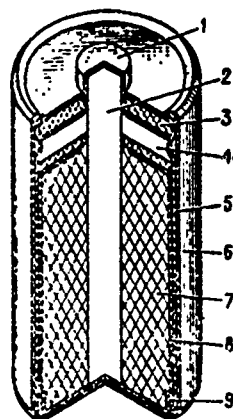


Figure 4. Can-type manganese-zinc cell:

1 -- button; 2 -- carbon core;
3 -- tar cap; 4 -- gas space;
5 -- zinc can; 6 -- paper casing;
7 -- positive electrode of manganese dioxide; 8 -- gasket between positive and negative electrodes saturated with electrolyte;
9 -- cardboard disc on the bottom of zinc can.

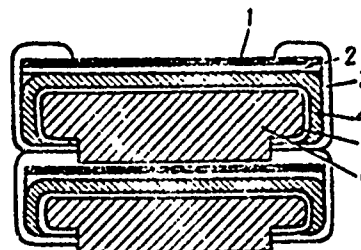


Figure 5. Design of pancake battery:

1 -- bipolar electrical conducting layer; 2 -- zinc electrode; 3 -- vinyl chloride casing; 4 -- cardboard diaphragm with electrolyte; 5 -- paper gasket; 6 -- positive electrode.

In the can-type cells manufactured under ordinary methods, the electrolyte in the form of a paste, occupies the space between the mass of the positive electrode and the zinc can. In the cells which are manufactured according to the new so-called tamped method (the positive electrode is wrapped with paper and pressed), it has been possible to raise the capacitance by reducing the distance between the electrodes and increasing the bulk of the positive electrode.

On the outside, the zinc can is wrapped in a cardboard, plastic or tin jacket.

In the pancake cell, as a positive electrode, they use a manganese dioxide pellet; a cardboard gasket between the pellet and the zinc plate which is the negative electrode is saturated with the electrolyte. The outside of the zinc plate is covered with a special electrical conducting layer which provides a good electrical contact in connecting the pancake cells into a battery.

A pancake cell has a covering from vinyl chloride film which at the same time is the frame and provides the necessary mechanical strength for the entire assembly of the pancake cell and its insulating.

The assembly of the pancake cells into a battery is done by placing the protrusion of the positive electrode pellet of one pancake on the recessed electrical conducting layer of the negative electrode of another.

Several cells connected in this manner make up a block which is carefully packaged in insulating material.

A battery of pancake cells, like a can-type battery, is formed from individual blocks by their series or parallel connection.

Tables 8 and 9 give the basic characteristics of the manganese-zinc cells and batteries with a chloride electrolyte which are produced by our industry.

The data given in the table in a majority of instances are based on the existing technical specifications. Certain data for a number of cells and batteries, for example, capacitance and specific characteristics, have been determined on the basis of the rated characteristics from the load impedance, operating time, and so forth. For this reason, in using a cell or battery under conditions which differ from those indicated in the tables, it is essential to refer to the graphs which are characteristic for this type of cell or battery and which give the dependency of capacitance upon discharge current and temperature.

The capacitance dependency of the MTs cells upon the discharge current is given in Figure 6. Figure 7 shows the temperature dependency of the cell capacitance.

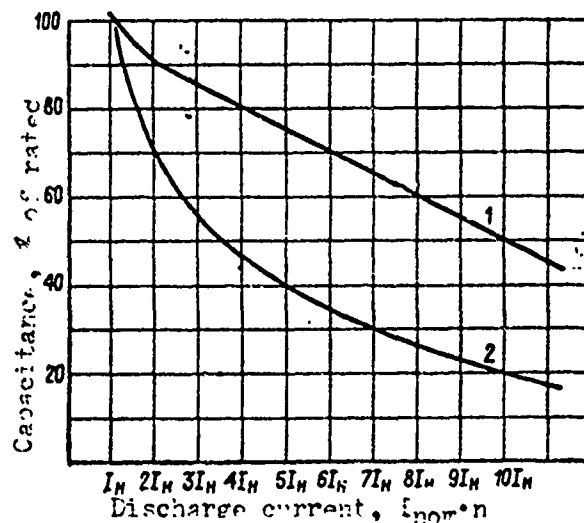


Figure 6. Dependency of capacitance produced by MTs cells upon discharge current.

1 -- can-type MTs cells; 2 -- pancake MTs cells.

In terms of their operating capabilities, the MTs cells and batteries are divided into "1" cells, that is, of the summer type with a temperature range of from -20° to $+60^{\circ}$ centigrade and "u" cells which are universal ones operating in a broad temperature range from -40° to $+60^{\circ}$ centigrade.

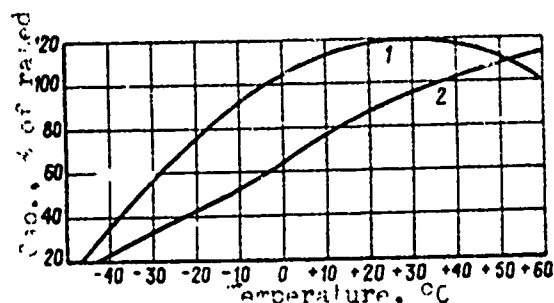


Figure 7. Dependency of capacitance produced by MTs cells upon temperature:
1 -- can-type MTs cells; 2 -- pancake MTs cells.

The dry cells of the MTs system with a salt electrolyte possess good shock resistance and can stand a load with an acceleration of 120 g. and a vibration load with an acceleration from 2 to 4 g. in a frequency range of from 10 to 70 hertz.

The cells manufactured by the tamped method (in the tables they are designated with numbers) are significantly superior in specific energy to the conventional type cells, including the pancake ones.

The new cells, as a rule, can operate in a broad temperature range of -40° to $+50^{\circ}$. This is a feature for the better in comparison with the cells and batteries manufactured in previous years.

In addition to the MTs cells and batteries, it is essential to note the air-zinc (VTs) cells and batteries with an alkaline electrolyte. Here the role of the positive electrode is played by air oxygen. The MTs and VTs cells with an alkaline electrolyte show a significant improvement in the performance of dry cells and batteries. These improvements have been expressed primarily in a significant increase in the service life and shelf life of the cells as well as by a rise in the specific energy.

A distinguishing feature of the new cells and batteries with an alkaline electrolyte is the possibility of their recharging. This significantly broadens the range of their use in small-sized equipment.

The new Finish battery which is designed for powering transistorized radio receivers, for example, can be recharged 25 times with a capacitance equal to 10 percent of the rated capacitance of the first discharge.

Figures 8 and 9 show the design of an VTs pancake cell with an alkaline electrolyte and an MTs cell of the button design.

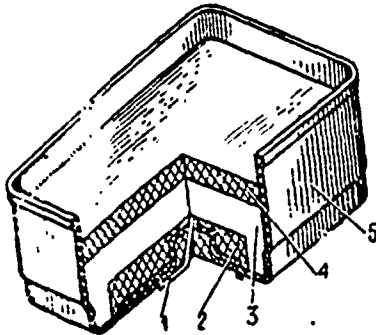


Figure 8. An air-zinc pancake cell:
 1 -- current drain of negative electrode; 2 -- zinc negative electrode; 3 -- diaphragm from alkali paste; 4 -- positive carbon electrode; 5 -- vinyl plastic casing.

The batteries of the VTs and MTs systems provide an opportunity to sharply increase the length of use in equipment, in comparison with batteries using a salt electrolyte. For example, the new KBS battery of frame design surpasses the KBS-1-0.5 battery by 300 percent in terms of discharge time, while the Sinichka battery which is the same size as two KBS-1-0.5 batteries surpasses the latter with an equal voltage by 200 percent in terms of length of operation.

The discharge characteristics for this type of battery are given in Figure 10, while the basic characteristics of the MTs and VTs cells and batteries with an alkaline electrolyte are given in Table 10.

Abroad, great attention is being paid to the development of air-zinc and oxygen-zinc (KTs) voltaic cells. For example, in the U.S., an air-zinc voltaic battery has been developed consisting of cells having two cathode plates and one anode plate from porous zinc. The cathode plates in this cell are called "air-breathing." The electrolyte is an alkaline one, a 30 percent solution of KOH. In addition to the high specific characteristics of this type of VTs cell, another distinguishing feature is the fact that the cells are recharged by the mechanical replacement of the worn out zinc electrode with a new one. The voltaic oxygen-zinc battery possesses even higher specific characteristics.

The new KTs cells, like the VTs cells, consists of two hydrophobic cathode plates and one anode porous zinc plate. In this cell, the role of the positive electrode is played by oxygen supplied to the cell under a high pressure from a tank. Regardless of the need to use a tank with

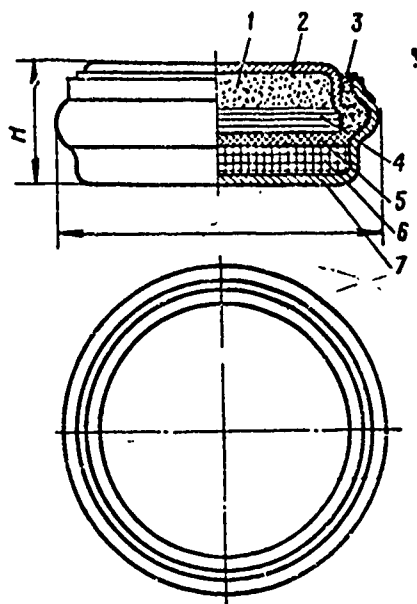


Figure 9. Design of a manganese-zinc button cell with an alkaline electrolyte: 1 -- negative electrode from zinc powder; 2 -- cap (positive pole); 3 -- packing ring; 4 -- diaphragm saturated with electrolyte; 5 -- separation gasket; 6 -- positive electrode from manganese dioxide; 7 -- housing (positive pole).

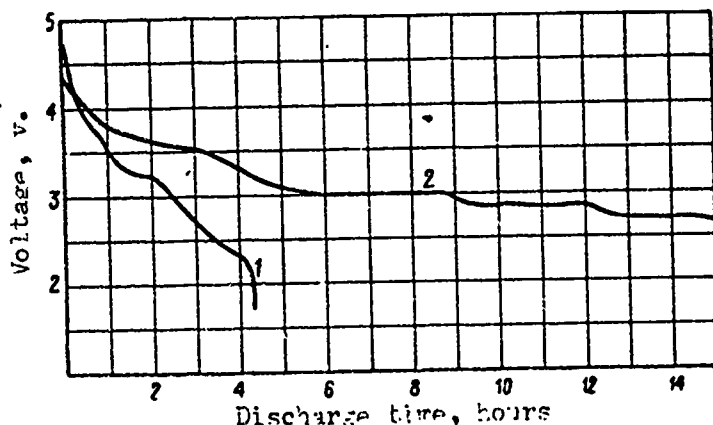
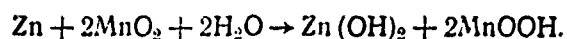


Figure 10. Comparative discharge characteristics for the KBS-u-0.5 battery of can design (1) and the KBS battery of frame design with an alkaline electrolyte; (2) under interrupted discharge conditions (10 minutes a day).

liquid oxygen and the related special strength of the cell due to the increase in the thickness of the vessel walls which as a whole lead to an increased weight, the new KT's cell, in terms of specific energy, surpasses the ST's storage battery by 500 percent. This is illustrated by the following data:

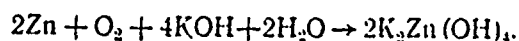
Type of Battery	Energy, wt-hr	Specific Energy, wt-hr/kg	Charge time, hrs	Weight, kg
VTs A-25-AN-24	600	132	0.17	4.5
KTs	25,000	335	--	58
STs VVCh51/I	430	66	10	7.2

The current-forming reaction in the manganese-zinc cells both with a salt (chloride) as well as with an alkaline electrolyte, can be represented by the formula:



In practical terms, in the cells processes occur which take place with the interaction of the zinc with the electrolyte, but they are not given here.

In cells of the air-zinc design, where air oxygen is the positive electrode, the electrochemical reaction is determined by the equation:



Among the drawbacks of the manganese-zinc dry cells is the self-discharge in the storage process. For certain types of cells the losses reach almost 30 percent of capacitance per year. Another drawback of these cells is the instability of the discharge voltage, more accurately, its great fall in the discharge process.

According to information of foreign authors, a sharp reduction in the self-discharge of cells and batteries with a salt electrolyte can be achieved by storing them at a low temperature. Thus, according to the data given in the press, in storing the MTs cells at a temperature of -54° , the capacitance losses during 10 years of storage were only 25 percent. The cells stored at the same time at a temperature of -12° centigrade lost 70 percent of capacitance, and at 0° centigrade, they lost all capacitance. The same cells which were stored at a temperature of $+21^\circ$ centigrade lost all capacitance after five years of storage.

With all their trouble-free qualities, the MTs and VTs dry cells and batteries still require the observance of elementary handling rules, particularly if the consumer proposes recharging them. This means that the cells and batteries should not be discharged below 0.9 volts per cell, the batteries should not be stored in a warm place near furnaces or radiators, and the cells and batteries should not be stored in a humid atmosphere or in an area where work is being done with various chemicals.

Soviet industry produces battery sets for powering radio receivers. These contain batteries for powering the anode and filament circuits and sometimes the grid. The characteristics of the battery sets are given in Table 11. From the data of Table 11, we can see the obvious advantages of a battery with an alkaline electrolyte.

Mercury-Zinc Cells and Batteries

The appearance of the new mercury-zinc (RTs) voltaic cells was caused by the rapid development of portable transistorized radio and sound recording equipment, where size and weight play the decisive role.

Among the chemical sources of current, the RTs cells do not have any rivals in terms of specific energy, in terms of the stability of characteristics during storage and discharging and in terms of convenience and simplicity in use, since they are among the dry sealed cells.

The design of a mercury-zinc cell is shown in Figure 11.

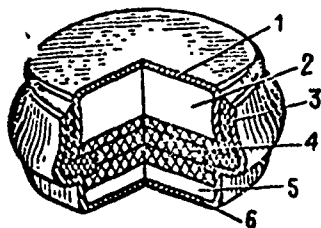


Figure 11. Design of a mercury-zinc cell:

- 1 -- top (negative pole);
- 2 -- zinc electrode;
- 3 -- rubber packing ring;
- 4 -- paper saturated with electrolyte;
- 5 -- mercury electrode;
- 6 -- housing (positive pole).

The active mass of the positive electrode of the cell consists of mercury oxide with the addition of graphite, while the negative electrode is of powdered zinc with a small quantity of mercury. The positive mass is pressed into the casing of the cell, while the negative is pressed into the top. Before assembling the cell, a gasket of porous paper saturated with the electrolyte consisting of a solution of potassium hydroxide with zinc oxide is inserted between the casing and the top. Between the top and the casing there is also a rubber insulating gasket which at the same time is the sealing packing.

Due to the absence of current drains, the losses within the cell are reduced to a minimum. This provides a low internal resistance of the cell, and consequently, the possibility of discharging with a current of increased density without a marked decline in the discharge voltage.

The electrochemical reaction in a mercury-zinc cell occurs according to the formula:



Dry Manganese-Zinc

1 Наименование, условное обозначение	2 Характеристики свежензготовленных изделий								
	3	4 Емкость, а·ч		5 условия разряда при +20°C					
		7	8	6 непрерывный			7 прерывистый		
				10 нагрузка, ом	11 ток разряда, ма	12 время разряда, ч	10 нагрузка, ом	11 ток разряда, ма	12 время разряда, ч

1.3-FVTS-0.25 1.3-ФМЦ-0.25
1.5-FVTS-60ch 1.5-СТМЦ-60ч
1.5-FVTS-0.6 1.5-СНМЦ-0.6

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КБ (КБ-1) КБ (КБ-1)
1.6-FVTS-3.2 1.6-ФМЦ-у-3.2

			about				Cells	Эле
283	1.50	ок. 0,1	ок. 0,015 (-20°)	—	—	—	3,5	28
286	1.48	ок. 0,15	ок. 0,01 (-40°)	200	ок. 7	20	300	ок. 5 60
314	1.52	ок. 0,3	ок. 0,03 (-40°)	200	ок. 7	38	300	ок. 5 75
312	1.52	ок. 0,16	ок. 0,02 (-20°)	—	—	—	—	3,5 60
316	1.52	ок. 0,4	ок. 0,04 (-40°)	200	ок.7	60	300	ок. 5 130
	1.30	0.25	—	—	150	—	—	—
	1.50	ок. 0,4	—	200	ок. 7	60	—	—
	1.52	0.6	—	25	ок. 60	12	—	—
326	1.52	ок. 0,7	ок. 0,07 (-40°)	200	ок. 7	100	300	ок. 5 200
332	1.40	—	(-40°)	—	—	6	5	ок. 1,5
336	1.40	—	(-40°)	—	—	10	5	ок. 230. 3,5
343	1.55	ок. 0,9	ок. 0,1 (-40°)	20	ок. 75	12	5	ок. 230. ок. 4
	1.60	1.05	—	117	ок. 14	—	—	—
	1.60	3.2	0.3 (-40°)	10	ок. 150	32	—	—

- Key:
1. Code name
 2. Characteristics of newly manufacture article
 3. Voltage, volts
 4. Capacitance, a-hr
 5. Discharge conditions at +20° C.
 6. Continuous
 7. Interrupted
 8. at +20° C.
 9. below zero
 10. load, ohms
 11. Discharge current, ma
 12. Discharge time, hours

Table 8

Cells and Batteries

Конечное напряжение раз- ряда, в	14	Гарантийный срок хра- нения, мес	16 Характеристики в конце срока хранения					17 Габариты, мм			18 Удельная энергия (для непрерывного режима раз- ряда)		
			20 на- пряже- ние, в	21 ем- кость, а · ч	длитель- ность раз- ряда		25	26 ширина (диаметр)	27 высота				
					22	24							
				непрерыв- ный, ч	прерыва- емый, ч	длина				по объему, г · ч $\frac{г · ч}{см^3}$	по весу, $\frac{г · ч}{кг}$		

Модели Cells

0,9	3	—	0,08	—	—	—	10,5	22	4,5	73	29
1,0—0,9	3	—	ок. 0,1	16	48	—	10,5	44,5	10	53	19
1,0—0,9	6	—	ок. 0,24	30	60	—	14,5	38,0	15	64	26
0,9	6	—	ок. 0,12	—	—	—	14,5	25	10	52	21
1,0—0,9	9	—	ок. 0,3	48	100	—	14,5	50,5	20	65	26
0,6	6	1,2	0,17	—	—	—	21,1	36,0	30	23	14
1,0	6	—	—	—	—	—	16	50	25	58	19
1,0	6	—	0,4	8	—	—	20	60	40	38	16
1,0—0,9	6	—	ок. 0,55	75	150	—	16	50,5	25	84	34
0,75	6	—	—	4,8	1,1	—	21,5	37,0	30	39	16
0,75	6	—	—	7	ок. 3	—	21,5	60,0	45	44	16
0,75 0,85	18	—	ок. 0,8	9	3,3	—	26	50	52	42	22
1,0	8	—	0,7	—	—	—	21	60	45	61	28
0,7	12	1,32	2,6	26	—	—	34	61,5	105	66	37

Key:

14. End discharge voltage, v.
 15. Guaranteed shelf life, mo.
 16. Performance at end of shelf life,
 17. Dimensions, mm
 18. Weight, grams
 19. Specific energy (for continuous discharge conditions)
 20. Voltage, v.

21. Capacitance, a-hr.
 22. Length of discharge
 23. Continuous, hours
 24. Interrupted, hours
 25. Length
 26. Width (diameter)
 27. Height
 28. For volume, w-hr/dm³
 29. For weight, w-hr/kg

		2 Характеристики свежеработанных изделий									
		3			5 условия разряда при +20°C						
		4 Цена, и. ч			6 непрерывный			7 прерывистый			
1 Наименование, условное обозначение		напряжени- е, в	при +20°C	ниже нуля	нагрузка, ом	ток разряда, мА	время разр а, ч	нагрузка, ом	ток разряда, мА	время разряда, ч	
Mars			about								
373 („Марс“)		1.55	ок. 3	ок. 0.3 (-40°)	20	ок. 75	40	5	ок. 230	ок. 18	
374		1.55	ок. 4	ок. 0.4 (-40°)	20	ок. 75	50	5	ок. 230	ок. 22	
376		1.55	ок. 5	ок. 0.5 (-40°)	20	ок. 75	65	5	ок. 230	ок. 32	
1.58-SNMTs-17ch	1.58-СНМЦ-17ч	1.58	2.5	—	10	ок. 150	17	—	—	—	
1451 (2S-1-9)	145л (2С-л-9)	1.48	ок. 11	ок. 4.2 (-17°)	20	ок. 70	160	—	—	—	
145u (1.6-PMTs)	145y (1.6-ПМЦ)	1.60	ок. 11	ок. 4.2 (-40°)	20	ок. 70	160	—	—	—	
1651 (2S-1-30)	165л (2С-л-30)	1.50	ок. 38	ок. 8 (-17°)	20	ок. 70	550	—	—	—	
165u (1.66-TMTs)	165y (1.66-ТМЦ)	1.66	ок. 38	ок. 8 (-40°)	20	ок. 70	550	—	—	—	
Batteries Бата											
2.9-NMTs-1.5ch	2.9-НМЦ-1.5ч	2.9	ок. 0.1	—	40	ок. 70	1.6	—	—	—	
KBS-1-0.50	КБС-л-0.50	3.7	0.5	0.2 (-10°)	10	ок. 350	2	15	ок. 250	3.5	
KBS-kh-0.70	КБС-х-0.70	4.1	0.7	0.2 (-20°)	10	ок. 350	3	15	ок. 250	3.5	
4.2-SAMTs-5ch	4.2-САМЦ-5ч	4.2	ок. 1.7	—	10	ок. 350	5	—	—	—	
4.5-PMTsG-0.7	4.5-ПМЦГ-0.7	4.5	0.7	—	—	350	—	—	—	—	
5-PMTsG-1.5ch	5-ПМЦГ-1.5ч	5.0	ок. 0.05	—	110	ок. 35	1.5	1.5	—	—	
5.6-PMTsG-22ch	5.6-ПМЦГ-22ч	5.6	1.5	—	75	ок. 70	22	—	—	30	
7-PMTsG-0.06	7-ПМЦГ-0.06	7.0	0.06	—	1000	—	—	—	—	—	
Krona	Крона	9.0	0.15	—	—	ок. 10	15	—	—	—	
Krona 1L	Крона 1Л	9.0	0.25	—	—	ок. 10	20	900	—	—	

For Key: [See page 37.]

Table 8 (Con't.)

Конечное напряжение раз- ряда, в	Гарантийный срок хране- ния, мес	Характеристики в конце срока хранения					Габариты, мм			Вес, г	Удельная энергия (для непрерывного режима раз- ряда)		
		напряжение, в	емкость, а · ч	длитель- ность раз- ряда		длина	ширина (диаметр)	высота	по объему, вт · ч		по весу, вт · ч	по объему, вт · ч	по весу, вт · ч
				23	24								
0,85 0,75	18	—	about ок. 2,6	28	11,5	—	34	61,5	115	65	31		
0,85 0,75	18	—	ок. 3,2	35	12	—	34	75	130	71	37		
0,85 0,75	18	—	ок. 4	45,5	18,5	—	34	91	165	73	37		
1,0	10	—	2,0	10	—	—	36	101	160	40	25		
0,85	12	—	ок. 9	130	—	42	42	102	300	77	46		
0,85	18	—	ок. 9	130	—	42	42	102	300	77	46		
0,85	21	—	ок. 28	400	—	57	57	132	700	113	68		
0,85	21	—	ок. 28	400	—	57	57	132	700	113	68		

pen Batteries

2.3	10	—	0.07	1	—	48	26	70	110	3	2.3	
2.0	6	3.3	0.27	1.3	ок. 3	62	21	63	150	16	10	
3.7	8	3.7	0.38	2	ок. 3	62	21	63	150	27	15	
2.0	6	—	—	2.5	—	102	37	83	400	19	15	
3.0	12	—	—	—	—	55	40	45	350	25	7.5	
3.0	4	4	—	1	—	42	36	28	65	5	3	
3.8	8	—	—	16	20	80	50	57	340	30	20	
3.0	8	—	—	—	—	33	31	31	—	11	—	
6.0	6	—	—	—	—	26	16	49	35	57	32	
5.6	6	—	—	—	—	26	16	49	35	94	54	

For Key: [See page 38.]

1 Наименование, условное обозначение	2 Характеристики снежнотермоустойчивых изделий									
	3 напряжение, в	4 Цена, л. ч			5 условия разряда при +20°С					
		2 при +20°С	3 ниже нуля	4 ниже нуля	6 неперывный			7 прерывистый		
					10 нагрузка, Ом	11 ток разряда, мА	12 время разряда, ч	10 нагрузка, Ом	11 ток разряда, мА	12 время разряда, ч
GP-10-u-1.3	ГБ-10-y-1.3	10.0	1.3	0.16 (-40°)	700	ок. 14	120	—	—	—
11.5-PMTsG-u-1.3	11.5-ПМЦГ-y-1.3	11.5	1.3	0.095 (-40°)	780	ок. 14	—	—	—	—
13-AMTsG-0.5	13-АМЦГ-0.5	13.0	0.5	0.1 (-20°)	—	1	—	—	—	—
13-AMTsG-u-0.5	13-АМЦГ-y-0.5	13.0	0.5	0.1 (-40°)	10 к	ок. 1	500	—	—	—
19-PMTsG-0	19-ПМЦГ-0	19	—	—	14 к	ок. 1.3	—	—	—	—
22.5-PMTsG-60ch	22.5-ПМЦГ-60ч	22.5	0.15	—	9 к	ок. 2	60	—	—	—
31-SAMTsCh-0.02	31-САМЦЧ-0.02	31	0.02	—	50 к	ок. 0.6	40	—	—	—
48-PMTsG-64ch	48-ПМЦГ-64ч	48	ок. 0.2	—	14 к	ок. 3.4	64	—	—	—
49-SAMTsG-102ch	49-САМЦГ-102ч	49	0.25	—	25 к	ок. 2	100	—	—	—
60-PMTsG-0.15	60-ПМЦГ-0.15	60	0.15	—	35 к	ок. 1.4	—	—	—	—
67.5-AMTsG-u-0.06	67.5-АМЦГ-y-0.06	67.5	0.06	—	10 к	ок. 6	10	—	—	—
74-PMTsG-45ch	74-ПМЦГ-45ч	74	0.05	0.006 (-20°)	43 к	ок. 1.5	45	—	—	—
75-AMTsG-22ch	75-АМЦГ-22ч	75	ок. 0.2	—	8 к	ок. 9	22	—	—	30
75-PMTsG-80ch	75-ПМЦГ-80ч	75	ок. 0.2	—	28 к	ок. 2.6	80	—	—	—
80-AMTsG-30ch	80-АМЦГ-80ч	80	ок. 0.2	—	30 к	ок. 4	80	—	—	—
87-PMTsG-0.15	87-ПМЦГ-0.15	87	0.15	—	28 к	ок. 3	—	—	—	—
87-PMTsG-u-0.15	87-ПМЦГ-y-0.15	87	0.15	0.02 (-40°)	28 к	ок. 3	70	—	—	—
100-PMTsG-u-0.05	100-ПМЦГ-y-0.05	100	0.05	0.006 (-40°)	28 к	ок. 1.2	50	—	—	—
105-PMTsG-0.05	105-ПМЦГ-0.05	105	0.05	—	70 к	ок. 1.4	—	—	—	—
109-PMTsG-0	109-ПМЦГ-0	109	—	—	85 к	—	—	—	—	—
200-PMTsG-10ch	200-ПМЦГ-10ч	200	0.01	0.0016 (-20°)	—	1	10	—	—	—
230-PMTsG-350ch	230-ПМЦГ-350ч	230	0.01	0.006 (-10°)	6M	—	350	—	—	—
GB-400-0.01	ГБ-400-0.01	400	0.01	0.0003 (-40°)	—	ок. 1	—	—	—	—

For Key: [See page 37.]

Table 2 (Cont.)

Конечное напряжение раз- ряда, %	14	15 Гарантийный срок хране- ния, мес	16 Характеристики в конце срока хранения				17 Габариты, мм			18 Вес, г	19 Удельная емкость (в пересчете на разряды)	
			20 напряжение, в	21 емкость, а · ч	22 длитель- ность раз- ряда		25 длина	26 ширина (диаметр)	27 высота		28 по объему, а · ч	29 по массе, а · г
					23 непрерыв- ный, ч	24 прерыв- ный, ч						
5.7	15	7.9	1.05	92	—	—	54	49	59	250	70	42
6.5	8	8.0	1.0	—	—	—	56	50	63	330	55	34
8.0	12	—	0.35	—	—	—	70	52	42	250	42	26
8.0	18	—	—	—	—	—	65	51	41	250	50	26
—	4	—	—	15	—	—	69	29	19	50	—	—
15	6	—	0.1	40	—	—	79	35	24	100	56	32
20	6	—	0.007	14	—	—	34	20	46	40	20	15
30	8	40	—	40	—	—	48	39	95	250	56	40
30	10	—	0.15	60	—	—	45	36	100	250	61	40
40	6	—	0.01	—	—	—	78	40	69	250	42	36
48	6	—	—	—	—	—	62	33	67	250	26	16
48	6	—	0.02	30	—	—	94	35	39	160	30	23
45	8	—	—	16	20	—	95	40	70	360	56	41
50	6	65	—	60	—	—	52	42	142	380	48	39
50	10	—	—	60	—	—	71	46	75	400	65	40
50	6	—	0.12	—	—	—	74	26	150	400	47	34
50	12	—	—	—	—	—	73	25	150	450	49	30
70	12	—	—	—	—	—	77	28	77	250	30	20
70	6	100 (в.к.)	0.02	—	—	—	77	28	77	180	30	28
—	6	97	—	—	—	—	47	111	300	—	—	—
125	6	—	0.005	—	—	—	65	37	47	135	17	15
163	6	—	—	200	—	—	97	29	36	200	18	9
250	6	—	0.005	—	—	—	87	63	35	250	20	16

For Key: [See page 32.]

Dry Manganese-Zinc Batteries

1 Наименование, условное обозначение	2 Характеристики свежензготовленных изделий	3 напряжение, в	4 емкость, а · ч		5 условия разряда при +20° C					
			а	б	6 непрерывный			7 прерывистый		
					10	11	12	10	11	12
			при + 20° C	ниже нуля	R нагрузки, ом	ток разряда, ма	время, ч	R нагрузки, ом	ток разряда, ма	время, ч
1.46-AMTsG-60ch	1.46-НМЦГ-60ч	1,46	25	—	at cut	—	—	—	—	—
3-AMTsG-8ch	3-НМЦГ-8ч	3,0	4,5	1,3	30	ок. 400	60	—	—	—
				(-20°)	6	ок. 450	10	—	—	—
3.0-AMTsG-u-110	3.0-МЦГ-у-110	3,5	110	—	6,6	ок. 500	385	6,6	ок. 500	390
"Meteor"	"Метеор"	6	3	0,3	13,3	150	20	—	—	—
				(-20°)	—	—	—	—	—	—
Zarnitsa	"Зарница"	7,5	170	—	30	ок. 250	700	—	—	—
18-AMTsG-0.3	18-ПМЦГ-0.3	18	0,3	—	1800	ок. 10	180	—	—	—
18-AMTsG-0.7	18-ПМЦГ-0.7	18	0,7	—	2 к	ок. 8	—	—	—	—
23-AMTsG-180ch	23-ПМЦГ-180ч	23	ок. 2	—	1800	ок. 11	180	—	—	—
25-AMTsG-0.6	25-ПМЦГ-0.6	25	0,6	—	270	ок. 75	—	—	—	—
25-AMTsG-0.8	25-ПМЦГ-0.8	25	0,8	—	480	ок. 40	—	—	—	—
29-GRMTs-13	29-ГРМЦ-13	29	13	—	—	—	60	—	—	28
69-GRMTs-6	69-ГРМЦ-6	69	6	—	—	—	288	—	—	35
BAS-g-60-u-1.3	БАС-Г-60-у-1,3	70	1,3	0,16	4680	ок. 15	120	—	—	—
				(-40°)	—	—	—	—	—	—
BAS-G-60-l-1.3	БАС-Г-60-л-1,3	70	1,3	0,3	4690	ок. 15	120	—	—	—
				(-20°)	—	—	—	—	—	—
90-AMTsG-0.15	90-ПМЦГ-0.15	90	0,15	—	38 к	ок. 2	—	—	—	—
102-AMTsG-120ch	102-АМЦГ-120ч	102	1,2	—	7 к	ок. 14	120	—	—	—
100-AMTsG-0.7	100-АМЦГ-0.7	100	0,7	—	7 к	ок. 14	66	—	—	—
EAS-80-u-1	БАС-80-у-1	102	1,0	0,2	7 к	ок. 14	95	—	—	—
				(-40°)	—	—	—	—	—	—
EAS-80-u-2.1	БАС-Г-80-у-2,1	100	2,1	0,22	7 к	ок. 14	180	—	—	—
				(-40°)	—	—	—	—	—	—
EAS-G-80-l-2.1	БАС-Г-80-л-2,1	100	2,1	0,45	7 к	ок. 14	180	—	—	—
				(-20°)	—	—	—	—	—	—
120-AMTsG-0.15	120-ПМЦГ-0.15	120	0,15	—	70 к	ок. 1,4	—	—	—	—
120-AMTsG-60ch	120-АМЦГ-60ч	120	0,27	—	8750	ок. 13	60	—	—	—
120-AMTsG-0.35	160-АМЦГ-0.35	160	0,35	—	12 к	ок. 13	—	—	—	—
225-AMTsG-80ch	225-ПМЦГ-80ч	225	0,2	—	85 к	ок. 3	80	—	—	—
3E-300 No 4	ГБ-300 № 4	335	0,05	—	—	1	—	—	—	—
315-AMTsG-80ch	315-ПМЦГ-80ч	315	0,2	—	120 к	ок. 2,6	80	—	—	—
300-AMTsG-1000	330-ЭВМЦГ-1000	330	—	—	—	—	—	1000	включений	crains
Polniva	"Молния"									
450-AMTsG-0.06	450-ПМЦГ-0.06	450	0,06	—	0,5 M	1	—	—	—	—

Key:

1. Code letter
2. Performance of newly manufactured articles
3. Voltage, volts
4. Capacitance, amp-hours
5. Discharge conditions at +20° C.
6. Continuous
7. Interrupted
8. At +20° C.
9. Below zero
10. Load R, ohm
11. Discharge current, ma
12. Time, hours

Table 2

Dry Manganese-Zinc Batteries

Конечное напряжение раз- ряда, в	Гарантийный срок хране- ния, мес	Характеристики в конце срока хранения					Габариты, мм			Вес, кг	Удельная энергия (для непрерывного режима раз- ряда)	
		напряжение, в	емкость, а · ч	длитель- ность раз- ряда, ч		длина	ширина (диаметр)	высота	по объему, кг · ч дм³		по весу, кг · ч кг	
				27	28							
												19
0,9	12	—	—	45	—	180	45	106	1,3	35	23	
2,2	12	—	—	5	—	95	62	145	1,4	13,5	8,3	
1,5	12	—	—	308	312	181	95	205	5,3	79	52	
—	10	—	—	12	—	150	115	110	2,2	12	7	
4,2	15	—	—	450	—	250	170	180	10	134	102	
12	12	—	—	—	—	75	43	52	0,5	27	9	
12	12	—	—	—	—	115	50	58	0,55	31	19	
15	24	—	—	—	—	65	54	135	0,8	80	43	
16	12	—	—	—	—	95	64	82	0,65	24	19	
16	12	—	—	—	—	98	50	75	0,80	41	20	
14	12	—	7	—	14	342	287	200	20	20	19	
34	9	—	4	—	14	450	360	160	25	16	15	
40	15	55	1,05	92	—	174	112	50	1,6	88	53	
40	15	55	1,05	92	—	174	112	50	1,6	88	53	
63	7	—	0,1	—	—	95	45	75	0,45	37	26	
60	12	—	0,85	70	—	185	145	59	2,5	60	36	
60	15	70	0,57	54	—	174	117	53	1,7	52	33	
60	15	84	0,75	68	—	218	138	73	3,0	36	26	
60	15	84	1,6	149	—	218	138	73	3,0	70	52	
60	15	84	1,6	149	—	218	138	73	3,35	68	41	
82	7	—	0,1	—	—	150	38	70	0,58	56	26	
56	6	—	0,2	40	—	240	94	40	1,3	30	21	
100	6	—	0,24	—	—	109	77	144	1,8	41	28	
150	6	195	—	60	—	86	63	147	1,0	50	40	
220	4	285	—	—	—	80	60	145	0,65	23	24	
210	6	270	—	60	—	80	80	155	1,3	56	42	
240	6	—	700 включений crains			120	62	132	1,4	—	—	
302	6	—	0,03	—	—	162	50	74	0,8	41	31	

Key:

- | | |
|---|--------------------------------------|
| 13. End discharge voltage, v. | 20. Capacitance, amp-hours |
| 14. Guaranteed shelf life, mos. | 21. Duration of discharge, hou |
| 15. Performance at end of shelf life | 22. Continuous |
| 16. Dimensions, mm | 23. Interrupted |
| 17. Weight, kg. | 24. Length |
| 18. Specific energy (for continuous discharge conditions) | 25. Width (diameter) |
| 19. Voltage, v. | 26. Height |
| | 27. For volume, w-hr/dm ³ |
| | 28. For weight, w-hr/kg |

Table 10

Manganese-Zinc and Air-Zinc Dry Cells and Batteries with an Alkaline Electrolyte

1	2				3			4			5			6			7	
	Характеристики свежизготовленных элементов и батарей				Гарантийный срок хранения, мес.			Характеристики в конце срока хранения			Характеристики в конце срока хранения			Габариты, мм			Удельная энергия	
	напряжение, в	емкость, а-ч	сопротивление, ом	ток разряда, мА	время разряда, ч	напряжение в конце разряда, в	напряжение в конце срока хранения, в	напряжение, в	емкость, а-ч	сопротивление, ом	длительность хранения, мес.	длина	ширина (диаметр)	высота	Dec. 2	по объему, г/см ³	по весу, г/см ³	№
НТС																		
Button-Type Manganese-Zinc Cells																		
Марганцево-цинковые элементы пугочинного типа																		
МЦ-1К	1.46	0.11	0.01	500	2.5	45	0.8	15	1.36	0.007	30	—	Ø15.5	6.6	4.1	105	33	
МЦ-2К	1.46	0.3	0.03	500	2.5	125	0.8	15	1.36	0.187	75	—	Ø21.0	7.4	8.2	145	45	
МЦ-3К	1.46	0.4	0.05	117	10	40	0.8	15	1.36	0.25	25	—	Ø25.5	8.4	14.5	121	36	
МЦ-4К	1.46	1.0	0.1	117	10	100	0.8	15	1.36	0.60	60	—	Ø30.1	9.4	21.5	196	61	
НТС																		
Sub-Type Manganese-Zinc Cells																		
Марганцево-цинковые элементы стаканчикового типа																		
МЦ-7-I	1.45	7	3	7.5	200	45	1.0	15	—	—	—	80	35	63	300	52	30	
МЦ-7-II	1.45	7	3	7.5	200	45	1.0	15	—	—	—	40	40	100	300	56	30	

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Key:

1. Cell (battery) name
2. Performance of newly manufactured cells & batteries
3. Guaranteed shelf life, mos.
4. Performance at end of shelf life
5. Dimensions, mm
6. Weight, g
7. Specific energy
8. Voltage, v.
9. Capacity, a-hr
10. At +20°C
11. Below zero
12. Load, ohm
13. Discharge current, ma
14. Discharge time, hrs.
15. Voltage at end of discharge, volts.
16. Voltage, v.
17. Capacitance, a-hr.
18. Length of dis. hr.
19. Length
20. Width (diameter)
21. Height
22. For vol. w-hr/dm³
23. For weight w-hr/kg

Table 10 (Cont.)

1 Наименование элемента (батареи)	2 Характеристики смежных элементов и батарей										3 Характеристики в конце срока хранения				4 Габариты, мм			5 Вес, г		6 Удельная энергия	
	напряжение, В	емкость, а·ч	ниже нуля	сопротивление, Ом	ток разряда, мА	время разряда, ч	напряжение в конце разряда, В	срок хранения, мес	исправление, %	емкость, а·ч	ангельность, ч	длина	ширина (ангель)	высота	Вес, г	по объему, г/л	по весу, г/л	Удельная энергия	Удельная энергия	Удельная энергия	Удельная энергия
045	1.30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
076	1.30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Марганцево-цинковые и воздушно-цинковые батареи																					
Крона Уте "Крона ВЦ"	9.0	0.5	—	900	10	60	6.0	12	—	0.25	30	16	26	49	40	200	100	—	—	—	—
"Финиш"	9.0	0.9	—	900	10	100	6.0	—	—	—	—	26	21	62	60	210	120	—	—	—	—
КБС рамочной	4.5	2.5	—	300	16	3.7	—	—	—	—	—	63	22	65	200	110	50	—	—	—	—
конструктив	9.0	0.25	—	200	40	70	6.0	—	—	—	—	72	24	126	250	92	80	—	—	—	—
"Синичка"	9.0	10.0	—	435	18	600	6.0	12	—	—	250	108	54	140	900	155	120	—	—	—	—
"Пионер"	9.0	35.0	—	435	18	2000	6.0	12	—	—	—	105	116	206	3300	85	80	—	—	—	—
"Полет"	9.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Note: 1. The data for the discharge time are given for continuous conditions. 2. The Finish battery can be recharged 25 times with a discharge duration of 10 hours.

Key: [See page 45.]

Battery Sets for Powering Radio Equipment

1	2	3	4 Характеристики свежизготовленных бата							
			7	8	9	10	длительность 5 разряда, ч			
							6	12		
								при +20°C	при +40°C	прерывистый
Условное обозначение комплекта	Конструкция	Электролит	напряжение, в	емкость, а.ч	сопротивление на- грузки, ом	ток разряда, ма	при +20°C	при +40°C	прерывистый	
65-AMMTs-1.3II										
65-AMMT-1.3-II	Pan	Salt								
анодная часть	Гал.	Сол.	65	1,3	4680	—	120	—	725	
накальная "	Стак.	"	2,5	29,5	20	—	280	—	725	
filament	Cup	"								
150-AMMTs										
анодная часть	Гал.	"	150	0,04	—	15	3	—	—	
накальная "	Стак.	"	1,5	1,2	—	400	3	—	—	
54-ASMTsG-5-II										
анодная часть	Гал.	"	54	5	800	67	120	—	1000	
сеточная "	"	"	4	5	60	67	120	—	1000	
grid	"	"								
123-ACMЦГ-60ч										
анодная часть	"	"	123	0,78	9000	13	60	—	—	
сеточная "	"	"	12,8	0,78	940	13	60	—	—	
ЕАНСС-18										
АНСС-18										
анодная часть	"	"	117	0,189	17300	7	27	2	—	
накальная "	Стак.	"	3,1	3,06	17,3	170	18	1,5	—	
сеточная "	"	"	1,58	—	117	10	—	—	—	
Vostok (VTs)										
"Восток" (BU)		Alk.								
анодная часть	Гал.	Щел.	86	ок. 4	15200	ок. 5	800	—	—	
накальная "	Стак.	"	1,20	ок. 340	2,7	ок. 420	800	—	—	
сеточная "	"	"	7,9	ок. 4	1425	ок. 5	800	—	—	
Smena (VTs)										
"Смена" (BU)										
анодная часть	Гал.	"	86	5	17300	5	1000	—	—	
накальная "	Стак.	"	1,29	450	2,7	450	1000	—	—	
сеточная "	"	"	7,9	5	1200	5	1000	—	—	

Key:

1. Set code
2. Design
3. Electrolyte
4. Performance of newly manufactured batteries
5. Length of discharge, hrs.
6. Continuous
7. Voltage, volts
8. Capacitance, amp-hours
9. Load R, ma
10. Discharge current, ma.
11. At +20° C.
12. At -40° C.
13. Interrupted

Table 11

Battery Sets for Powering Radio Equipment

рей	14 конечное напряжение разряда, в	15 Гарантийный срок хранения, мес	16 Характеристики в конце срока хранения				17 Габариты, мм			18 Вес, кг	19 Удельная энергия	
			21 напряжение, в	22 емкость, а-ч	20 длительность разряда, ч		25 длина	26 ширина	27 высота		28 по объему $\frac{\text{вт-ч}}{\text{дм}^3}$	29 по весу, $\frac{\text{вт-ч}}{\text{кг}}$
					23 непрерывный	24 прерывистый						
40 1,4	15 15	58 2,4	0,95 22	80 200	565 565	125	120	190	3,5	51	41	
115 1,15	6 6	— —	— —	2 2	— —	152 "	46	97	0,9	10	8,1	
27 2	15 15	49 3,7	3,5 —	80 —	700 700	225	85	235	7,0	61	38	
65 7	12 12	— —	— —	45 45	— —	280	53	85	1,65	71	52	
71 2,24 0,8	12 12 12	— — —	— — —	22 15 —	— — —	116	52	140	1,2	36	24	
60 0,91 6,0	15 15 15	78 1,15 7,2	— — —	500 500 500	— — —	236	170	100	5,0	182	145	
60 0,85 6	6 6 6	— — —	— — —	700 700 700	— — —	250	200	120	7,0	155	133	

Key:

14. End discharge voltage, v
 15. Guaranteed shelf life, mos.
 16. Performance at end of shelf life
 17. Dimensions, mm
 18. Weight, kg.
 19. Specific energy
 20. Length of discharge, hours
 21. Voltage, v.

22. Capacitance, amp-hours
 23. Continuous
 24. Interrupted
 25. Length
 26. Width
 27. Height
 28. For volume, w-hr/dm³
 29. For weight, w-hr/kg

Figure 12 shows a family of discharge characteristics for several types of RTs cells. The positive qualities of the cells are voltage stability during discharge, particularly with low current densities. This makes it possible to use the RTs batteries and cells as sources of standard voltage. The discharge characteristics of a universal RTs cell at a temperature of -30° centigrade are given in Figure 13.

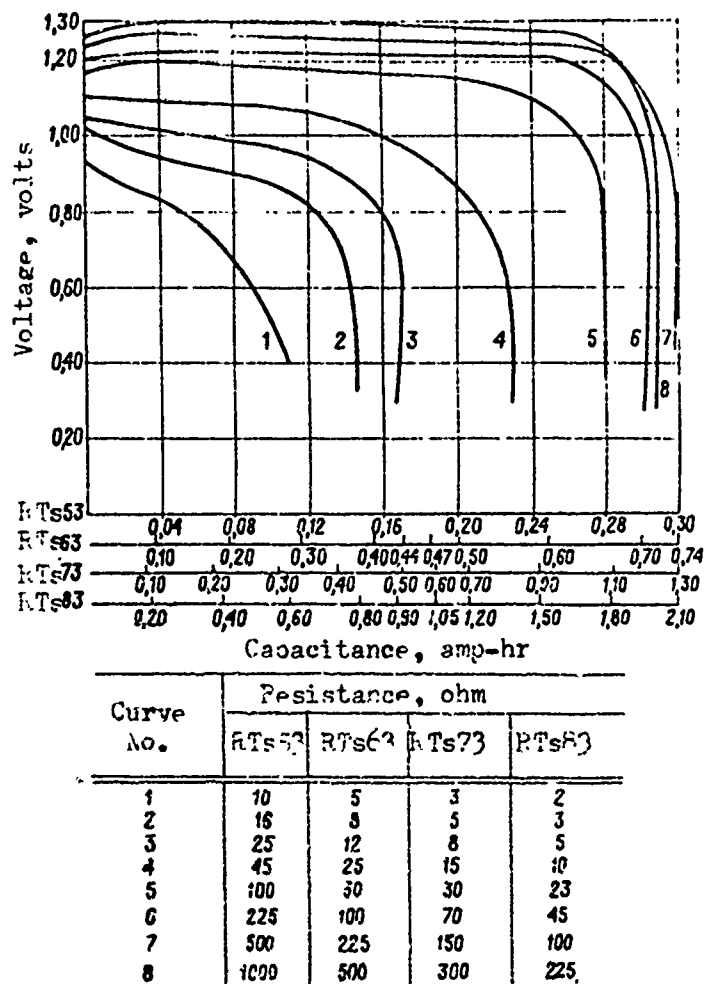


Figure 12. Universal discharge curves of RTs cells with various load resistances (at a temperature of $+20^{\circ}$ centigrade).

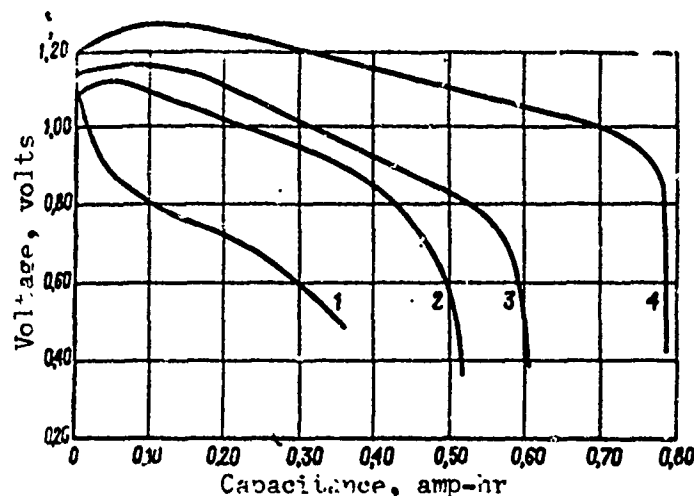


Figure 13. Discharge characteristics of a RTs85u cell at a temperature of -30° centigrade:
 1 -- 25-ohm load; 2 -- 50-ohm load; 3 -- 100-ohm load;
 4 -- 200-ohm load.

The self-discharge of the RTs cells is insignificant in the storage process. During a period from 12 months up to the end of the service life, the efficiency of the cells declines by not more than 10 percent.

The operating temperature range of the RTs cells lies within limits of from 0° to $+50^{\circ}$ centigrade for the conventional cells. For the universal-type cells designated with the letter "u," the operating range is from -30° to $+50^{\circ}$ centigrade, and for the heat-proof cells designated with the letter "t," from 0° to $+50^{\circ}$ centigrade.

In calculating the length of discharge for the conventional type of RTs cells designed for discharge in a temperature interval of from 0° to $+50^{\circ}$ centigrade, it is essential to consider the decline in capacitance, beginning at a temperature of $+15^{\circ}$ and lower. This decline is around four percent for 1° centigrade. This means that at a temperature of $+5^{\circ}$ centigrade, cells of the summer type not designated with the letter "u" produce around 60 percent of their rated capacitance. For universal-type cells, the capacitance losses with a continuous discharging are around 2.5 percent per degree centigrade, beginning with 0° centigrade and lower.

For the purposes of providing the operability of the RTs cells at low temperatures, it is advisable to use various heat-insulating casings or store the cells and batteries under garments and take them out for insertion into the equipment immediately before use.

In terms of mechanical properties such as resistance to blows, stability under the effect of vibration, and the ability to withstand both a vacuum to 10^{-6} mm Hg. as well as an increased pressure to 10 atm., the RTs cells hold one of the first places among the current sources. This determines the area of their use in military equipment, various field equipment, radiosondes, medical instruments and electric clocks.

Table 12 gives the characteristics of the RTs cells and batteries produced in the Soviet Union. The cells the numerical symbol of which terminates with the figure 3 are designed for operating under discharge conditions with increased current densities. This should be kept in mind in choosing the cell.

The mercury-zinc cells may be recharged within the shelf life, however the performance of cells charged by the consumer is not guaranteed by industry. The RTs cells can be charged with asymmetrical current, as is described in Chapter V.

The mercury-zinc cells, in terms of dimensions, conform to the manganese-zinc cells of the button type (Table 10). As a consequence of this, in choosing current sources for various equipment, it is advisable to use the MTs cells as backup sources, as their cost is significantly less than the cost of the RTs cells. Here it must be kept in mind that the capacitance of the MTs cells is almost 50-100 percent less than the same type of RTs cells.

The RTs-31 and RTs-32 mercury-zinc cells used for powering electric wristwatches have duplicates, the miniature ChMTs-2, ChMTs-3 and ChMTs-4 manganese-zinc cells, the dimensions of which conform to the RTs cells, but are inferior to the latter in terms of operating life.

Wet Cells and Batteries

Wet cells and batteries are sometimes called reserve since they can be put into use only after filling with the electrolyte. The electrolyte of the reserve cells can be liquid at an ordinary or low temperature. Some types of reserve cells require filling with an electrolyte consisting of dissolved salts. Such an electrolyte is called solid.

The reserve cells stand out in the very long service life in an unfilled state. After filling with the electrolyte, the service life of the cells depends upon the electrochemical couple and the design. It varies depending upon the type of cell from several seconds to 6-9 months.

The range of wet cells is comparatively slight, however the area of their use is rather broad. The heavy-duty wet batteries of the MOE and VD type are used for powering signal and communications equipment, both land and sea. The copper-magnesium and manganese-zinc batteries are used in radiosondes and geophysical equipment of various sorts. The characteristics of the wet cells and batteries are given in Table 13.

Table 12

Mercury-Zinc Cells and Batteries

1	2	3	4	5	6	7	8	9	10		11	12	13
									Время разряда, ч	Конечное напряжение, в			
Тип элемента (батареи)	Примечание наименование	Начальное напряжение, в	Номинальный ток разряда, мА	Емкость при +20°C, А·ч	Время разряда, ч	Напряжение, в	Конечное напряжение, в	Гарантийный срок хранения, мес	Габариты, мм		Вес, г	Удельная энергия, Вт·ч/г	14
									при +20°C	при 0°C			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
РЦ11	—	1.25	0.15	0.02	—	—	1.0	6	4.7	5.0	0.5	253	44
РЦ13	—	1.25	0.15	0.02	—	—	1.0	6	6.0	3.5	0.45	155	44
РЦ15	—	1.25	0.30	0.04	—	—	1.0	6	6.3	6.0	0.85	236	52
РЦ31	—	1.25	0.10	0.07	—	—	1.0	12	11.5	3.6	1.3	206	59
РЦ32	OP-OM-4	1.25	2.00	0.05	—	—	1.0	6	11.0	3.5	1.3	165	42
РЦ53	OP-OM-4	1.25	10.0	0.25	24	8	0.9	18	15.6	6.3	4.6	229	60
РЦ55	OPIK C ₂	1.22	10.0	0.50	50	15	0.9	30	15.6	12.5	9.5	230	58
РЦ57	OPI	1.25	20.0	1.00	—	—	1.0	12	16.0	17.0	15.0	294	67
РЦ59	—	1.25	60.0	3.00	—	—	1.0	12	16.0	50.0	44.0	327	75
РЦ63	OP2K	1.25	20.0	3.55	27	12	0.9	18	21.0	7.4	10.5	236	58
РЦ65	OP2	1.22	20.0	1.00	59	15	0.9	30	21.0	13.0	16.1	222	55
РЦ73	OP3K	1.25	30.0	1.00	32	12	0.9	18	25.5	8.4	17.2	257	58
РЦ75	OP3	1.22	30.0	1.50	55	15	0.9	30	25.5	13.5	27.0	240	61
РЦ82T	—	1.25	50.0X1.50	35	12	25	0.9	18	30.1	9.4	30.0	250	55

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Cells Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14
РЦ11	—	1.25	0.15	0.02	—	—	1.0	6	4.7	5.0	0.5	253	44
РЦ13	—	1.25	0.15	0.02	—	—	1.0	6	6.0	3.5	0.45	155	44
РЦ15	—	1.25	0.30	0.04	—	—	1.0	6	6.3	6.0	0.85	236	52
РЦ31	—	1.25	0.10	0.07	—	—	1.0	12	11.5	3.6	1.3	206	59
РЦ32	OP-OM-4	1.25	2.00	0.05	—	—	1.0	6	11.0	3.5	1.3	165	42
РЦ53	OP-OM-4	1.25	10.0	0.25	24	8	0.9	18	15.6	6.3	4.6	229	60
РЦ55	OPIK C ₂	1.22	10.0	0.50	50	15	0.9	30	15.6	12.5	9.5	230	58
РЦ57	OPI	1.25	20.0	1.00	—	—	1.0	12	16.0	17.0	15.0	294	67
РЦ59	—	1.25	60.0	3.00	—	—	1.0	12	16.0	50.0	44.0	327	75
РЦ63	OP2K	1.25	20.0	3.55	27	12	0.9	18	21.0	7.4	10.5	236	58
РЦ65	OP2	1.22	20.0	1.00	59	15	0.9	30	21.0	13.0	16.1	222	55
РЦ73	OP3K	1.25	30.0	1.00	32	12	0.9	18	25.5	8.4	17.2	257	58
РЦ75	OP3	1.22	30.0	1.50	55	15	0.9	30	25.5	13.5	27.0	240	61
РЦ82T	—	1.25	50.0X1.50	35	12	25	0.9	18	30.1	9.4	30.0	250	55

Key:

- Type of cell (battery)
- Previous name
- Initial voltage, V.
- Rate of discharge current, mA.
- Capacity at +20°C, amp-hours
- Discharge time, hours
- Load, ohm
- End discharge voltage, V
- Guaranteed shelf life, mos.
- Dimensions, mm.
- Weight, g.
- Specific energy
- At +20°C, - +500 C.
- At no C.
- Diameter
- Height
- For volume, w-hr/l
- For weight, w-hr/kg

Table 12 (Cont.)

1 Тип элемента (батарея)	2 Примечание наименование	3 Начальное напря- жение, в	4 Номинальный ток разряда, ма	5 Емкость при +20° и +50°С, а·ч	6 Время разряда, ч		7 Нагрузка, ом	8 Конечное напряжение разряда, в		9 Латентный срок хранения, мес	10 Габариты, мм		11 Вес, г	12 Удельная энергия	
					при +20° и +50°С	при 0°С		при +20° и +50°С	при 0°С		Диаметр	Высота		по объему, а·г/ч	по весу, а·г/кг
RTs PЦ83 PЦ84 PЦ85 PЦ93 PЦ85y	ОР ОР4К ОР4 Р-04 — —	1.25 1.22 1.22 1.25 1.22	50.0 50.0 50.0 300 50.0 12.5 (-30°)	1.50 2.50 2.50 13.0 2.50 —	35 50 55 — 55 —	12 15 15 20 — — (-30°)	25 — 25 — 25 — 100 (-30°)	1.0 1.0 1.0 1.0 1.0 — — (-30°)	0.9 — 0.9 — 0.9 — — (-30°)	18 30 30 6 18 —	30.1 30.1 30.1 31.0 30.1 —	9.4 14.0 14.0 66.0 14.0 —	28.2 45.0 39.5 170 39.5 —	250 276 276 316 276 —	59 61 70 84 70 —

Batteries Батареи

2PЦ63 5PЦ84	ОР2К 50Р4	2.50 6.0	60.0 100	0.55 3.0	5 —	1 —	40 —	0.9 4.5	0.6 —	12 —	22.0 35.0	16.0 85.0	21.1 250	194 170	58 55
12PЦ63/6 6PЦ63	12-ОР-2К —	16.0 7.2	100 10	0.5 —	15 50	— 30	150 600 (-30°)	11.0 5.4	— —	6 6	71×46×105 23	105 48	920 71	24 175	9 49

Key: [See page 52.]

Wet (Reserve) Cells and Batteries

1 Наименование	2 Электрохимическая система	3 Электролит	4 Э. Д. С., в	5 Напряжение, в	6 Емкость, ач	7 Время непрерывного разряда, ч
3-RZN-MTs-2ch	3-P3H-MЦ-2ч	Mn-Zn	—	3,0	about	2
21-RAZ-MTs-2ch	21-P3A-MЦ-2ч	Mn-Zn	—	21	ок. 0,2	2
3-MKhM-7ch	3-MXM-7ч	Mg-CuCl	—	3,0	0,004	7
200-PMKhM-2ch	200-ПМХМ-2ч	Mg-CuCl	—	—	ок. 1	—
anode	анод	NaCl	—	—	—	—
filament I	накал I	—	—	212	ок. 0,04	2
filament II	накал II	—	—	6,65	ок. 0,6	2
12-PMKhS-0.5ch	12-ПМХС-0,5ч	Mg-PbCl ₂	—	2,65	ок. 0,56	2
80-PMKhS-2ch	80-ПМХС-2ч	Mg-PbCl ₂	—	12,7	ок. 0,15	0,5
anode	анод	NaCl	—	—	—	—
filament	накал	—	—	90	ок. 0,03	2
MOE-250	МОЭ-250	Zn-CuO	—	3,3	ок. 0,2	2
MOEM-300	МОЭМ-300	Zn-CuO	0,9	0,65	250	500
MOE-500	МОЭ-500	Zn-CuO	0,84	0,65	300	300
MOEM-800	МОЭМ-800	Zn-CuO	0,9	0,65	500	500
MOEM-1000	МОЭМ-1000	Zn-CuO	0,84	0,65	800	530
MOE-1000	МОЭ-1000	Zn-CuO	0,84	0,65	1000	450
VD-300	ВД-300	Zn-C	0,9	0,65	1000	500
VD-500	ВД-500	Zn-C	1,4	1,2	300	—
VD-1000	ВД-1000	Zn-C	1,4	1,2	500	—
VDZh-50	ВДЖ-50	Fe-C	1,4	1,2	1000	—
VDZh-400	ВДЖ-400	Fe-C	1,0	0,75	50	—
Mayachok-1	„Маячок-1“	Mg-CuCl	1,0	0,75	400	—
Mayachok-2	„Маячок-2“	Mg-CuCl	—	2,95	1,6	10
3-KhS-15	3-XC-15	PbO ₂ -Pb	—	2,95	2,4	15
		HClO ₄	—	5,3	15	4

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Key:

1. Name
2. Electrochemical system
3. Electrolyte
4. Emf, volts
5. Voltage, volts
6. Capacitance, amp-hours
7. Time of continuous discharge, hours

Table 13

Wet (Reserve) Cells and Batteries

8	9	10		11			12		13
		14	15	16	17	18	19	20	
Ток разряда, а	Напряжение в конце разряда, в	Сохранность в сухом состоянии, мес	Сохранность в электролите, ч	длина	ширина	высота	сухих	заполненных электролитом	Примечание
about	1,5	48	2-3	39	39	36	0,055	—	Filled with water
ок. 0,1	15	48	2-3	62	39	36	0,095	—	Заливаются водой
0,002	2,4	24	2	37	31	60	0,080	—	Заливаются водой
ок. 0,14	178	24	2	150	138	80	0,85	—	Заливаются водой
ок. 0,02	5,45	24	2						
ок. 0,3	2,15	24	2						
ок. 0,26	10	15	4-5	46	36	49	0,067	0,082	Заливаются водой
ок. 0,3	72	12	4-5	96	58	85	0,275	0,32	Заливаются водой
ок. 0,014	2,52	12	4-5						
ок. 0,1	0,5	36	720						
0,5	0,55	36	720	180	170	350	3,8	—	Produced filled Выпускаются залитыми Выпускается залитым Заливаются водой Заливаются водой
1,00	0,5	36	720	133	133	212	4,4	—	
1,00	0,5	36	720	168	193	350	7,1	—	
1,5	0,55	36	720	200	200	237	8,5	—	
2,2	0,55	36	720	225	180	460	11,0	—	
2,0	0,5	36	720	232	180	460	12,5	—	
0,5	1,0	12	10000	186	110	312	4,5	—	
0,75	1,0	12	10000	190	165	345	6,2	—	
1,5	1,0	12	10000	222	178	446	10,6	—	
0,25	0,5	12	7000	—	Ø110	30	—	0,52	
0,5	0,5	12	7000	—	Ø221	75	—	5,0	Заливаются водой
0,16	1,8	24	20	21	43	100	0,085	—	
0,16	1,8	24	20	31	61	99	0,155	—	
3,0	4,7	24	5-6	175	92	123	—	4,0	

Key:

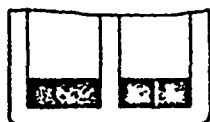
8. Discharge current, amp
9. Voltage at end of discharge, v.
10. Shelf life
11. Dimensions, mm
12. Weight, kg
13. Note
14. In dry state, mos.
15. Filled with electrolyte, hours
16. Length
17. Width
18. Height
19. Dry
20. Filled with electrolyte



Left panel dissolved in electrolyte. Cell 50 percent used.



Half of right panel dissolved. Cell 75 percent used.



All panels dissolved. Cell 100 percent used and ready for replacement.

Figure 14. Indicator panels in copper oxide cells.

A shortcoming of this type of cell is the low voltage and the impossibility of using it in transistorized equipment. In truth, the first of the listed drawbacks can be eliminated by treating the copper oxide in a weak (5 grams per liter) solution of sodium sulfide Na_2S . According to the information given by the author of this proposal, V. N. Flerov, the positive plates of the copper oxide cells activated with the Na_2S have an operating potential which is 25 percent higher than the ordinary serially-produced MOE. The voltage of the treated MOE is 0.84-0.75 volts.

Another type of wet cell with an alkaline electrolyte is the air depolarized VD cell. As the positive electrode, they use air oxygen, as is the case in the cells of the manganese-zinc system. Cast zinc serves as the negative electrode of the VD cell. The positive electrodes, for the purpose of creating a high porosity for greater oxygen diffusion, consists of a specially treated carbon mass. A solution of KOH with a density of 1.33-1.35 serves as the electrolyte of the VD cells.

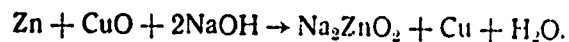
The comparatively high voltage of the VD cells, the good stability of the discharge characteristics and the low self-discharge with a significant shelf life makes these cells usable in stationary units, including those operating under low temperature conditions, since the working range of the VD elements lies within the limits of from $+40^\circ$ to -40° centigrade. The impossibility of transporting is the drawback of the VD cells, as is the case with the MOE cells.

Of the cells given in Table 13, the cells based on copper oxide are the most widely found, since the simplicity of design and trouble-free operation make it possible to use them in devices requiring high dependability. Moreover, the possibility of restoring the wornout positive copper plates for reuse is a positive feature in cells of this type.

The positive electrode of a copper oxide cell consists of a powdered copper oxide mixed in soluble glass. After a series of thermal treatments, the electrode acquires the necessary porosity and mechanical properties.

The negative electrode of the cell is cast, and consists of zinc with an admixture of mercury. Used as the electrolyte of the copper oxide cell is a solution of sodium hydrate with a density of 1.19-1.21 or potassium hydrate (at a temperature of -30° centigrade and lower) with a density of 1.26.

The chemical reaction in the copper oxide cell occurs according to the formula:



The copper oxide cells are produced in two modifications, the marine MOEM and the general-purpose MOE. The marine cells use as an electrolyte the solution of potassium hydrate. The cells are produced as blocks of plates, and the vessels are produced and delivered separately. For this reason, in using the copper oxide cells under stationary conditions, only the plate blocks are ordered as the cells wear out.

The degree of cell discharge is monitored visually. Monitoring is carried out by special indicator panels which are found on the negative electrodes. The degree of exhaustion of the cell is determined from the disintegration of the indicator panels (Figure 14).

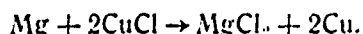
The emf of a copper oxide cell equals 0.9 watts. Voltage in the discharge process varies from 0.8 to 0.5 volts. However, the average discharge voltage is sufficiently stable and keeps within limits of 0.65 volts. This provides for the powering of equipment without using voltage stabilizers. Among the merits of the copper oxide cell is the long service life with virtually absent self-discharge, the high stability of the discharge characteristics and the relative inexpensiveness.

The desire to develop a cheap cell with electrodes from nonscarce materials has led to the development of an air depolarized cell with an iron anode. The VDZh cells use air oxygen as the positive electrode. The air is stored in a porous carbon electrode consisting of pulverized carbon with rubber and paraffin. Spongy iron is the negative electrode. The formation of a current occurs as a result of the oxidation of the iron. The electrolyte of the VDZh cell consists of a high-density KOH solution.

The VDZh cells have indisputable advantages in comparison with the other wet cells in terms of the amount of operating voltage; the high specific characteristics, and the low amount of self-discharge with protracted storage. Also among the merits of the VDZh cells is the possibility of transporting them, since they are put into a working state as they leave the plant. A drawback of the iron-carbon cells is their poor efficiency at a temperature below zero.

Manganese-zinc and copper-magnesium wet cells are used for powering equipment of radiosondes. The manganese-zinc cells in design terms do not differ from the MTs dry cells, and are put into use by filling with the electrolyte consisting of a solution of five weight parts of ammonium chloride in six weight parts of water with an admixture of one part alcohol. The alcohol is added for operating the battery under low temperature conditions with the ascent of the radiosonde into high altitude areas. After soaking for 20-60 minutes, the batteries are ready for use. The wet batteries should be used immediately, since their shelf life is limited in this state. The manganese-zinc wet cells of the RZN and RZA type can operate at a temperature of -25° centigrade, however their operational life at this temperature is reduced by 100 percent.

The copper-magnesium cells, although classified as wet cells, do not require filling with an electrolyte, but are wet with water before use, since chloride salts are present in the electrode materials. The positive electrode of the cell is copper chloride which has been pressed onto a copper grid, while the negative electrode is metallic magnesium. The current-forming reaction in the cell occurs following the equation:



Since an exothermic reaction with the production of heat occurs when the magnesium comes into contact with the water, all the magnesium cells operate efficiently at a temperature of from -50 to -70° centigrade. In terms of specific energy, the copper-magnesium cells are close to the conventional manganese-zinc can-type cell.

The cells where lead chloride is used and the positive electrode are another variety of magnesium cells. In contrast to the copper-magnesium cell, the voltage of which is 1.2-1.4 volts, a cell with lead chloride operates with a voltage of around one volt. In terms of the specific characteristics and operational temperature range, the lead chloride cells are analogous to the copper-magnesium cells.

The small sized Mayachok batteries (Figure 15) are very interesting in design terms. These batteries are activated by submersion in sea or river water. These batteries are classified among the magnesium and copper chloride electrochemical system, and are used for emergency rescue work, where a battery with a small light is fastened to a special life jacket or breastplate, and serves as a miniature beacon. The high specific characteristics of these batteries provide every reason for their extensive

use in miniature equipment operating under short-term use conditions.

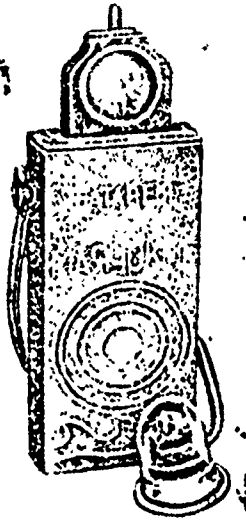


Figure 15. The emergency Mayachok-1 battery.

Among the cells of the magnesium group, the cells with a positive sulphur electrode have also attracted attention. This type of cell, although providing a low voltage of 0.7 volts, excels in a good shelf life in a dry form and in cheapness.

One of the cells of the sulphur-magnesium type designed for extended use is among the dry-type cells with an electrolyte of magnesium bromide. Although the cell has a low operating voltage (0.9 volts), its specific energy approximates the STs storage cells, while the discharge characteristics show good voltage stability. A drawback of the sulphur cells is the production of hydrogen sulphide during use. This limits the possibility of their use in interior areas.

The chlorine-silver-magnesium cells hold a special place in the magnesium cells. Here the chemical processes do not differ from the processes in the copper-magnesium and lead-magnesium cells, although the operating qualities make them irreplaceable in those types of equipment where a high current density must be obtained in a very short period of time. In terms of the operating capacity in brief discharge conditions, the chlorine-sulphur-magnesium [KhSM] cells surpass even the silver-zinc storage batteries, the discharge density of which is 0.4 amps per square centimeter of electrode surface. The KhSM cells tolerate discharging with a density of 0.8 amps per square centimeter. These cells are activated by fresh or sea water over a short period of time.

The operating voltage of the KhSM cells is significantly higher than the other cells of the magnesium group, and is 1.5 volts. The discharge characteristics, after voltage stabilization related to the wetting of the cells, show good constancy in a rather broad load range, including under operating conditions at temperatures down to -50° centigrade. The shelf life of the KhSM cells in a filled state is short, up to 48 hours.

The one-shot silver-zinc (STs) cells have found wide use in equipment requiring instantaneous activation of a source designed for discharging a heavy current in several seconds. In contrast to the silver-zinc storage batteries designed for protracted operation with a number of recharges, the one-shot STs cells are produced in a dry form, but with precharged electrodes.

As in the silver-zinc storage battery, the positive electrode of the STs cell is a silver oxide electrode which differs somewhat in design and manufacturing. The negative zinc electrode is manufactured either by precipitating spongy zinc on a foil base or by pressing a powder from zinc with mercury. The separation of the STs cells virtually does not differ from that used in the STs storage batteries, with the exception of the thickness of the film and the number of layers which for the STS cells are chosen as a minimum number, since the service life of the STs cells which have been filled with the electrolyte is short in terms of operating conditions.

The silver-zinc voltaic batteries are activated almost instantaneously by using a pyrotechnic device which presses the electrolyte out of a capsule into the vessels of the battery.

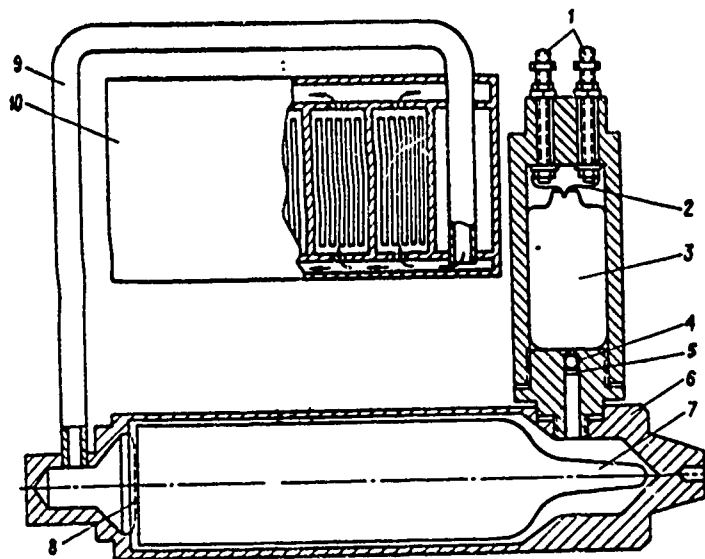


Figure 16. Diagram of the capsule STs battery with an ignition cylinder:

- 1 -- terminals for electric firing; 2 -- heater coil;
- 3 -- ignition cylinder; 4 -- metal ballbearing;
- 5 -- metal disc; 6 -- housing; 7 -- capsule with electrolyte; 8 -- screen; 9 -- tube; 10 -- battery.

The design of a battery with a pyrotechnic primer is shown in Figure 16. Here, upon command, the ignition cylinder is fired. The gases released with the explosion through the use of a ballbearing drive down a metal disc which breaks the capsule with the electrolyte. Other systems use compressed air or inert gases for delivering the electrolyte. Various warmers are used for operating under low temperature conditions.

Wet cells with positive electrodes based on lead, such as lead-zinc cells and lead-cadmium and lead cells with perchloric acid, are somewhat less widely used.

The lead-zinc cells are designed for powering heavy-duty units and provide a discharge with a current on the order of 100 amps and more. In the lead-zinc cells, sulphuric acid is the electrolyte. As a consequence of this, their service life in a filled state does not exceed four hours. The voltage of a lead-zinc cell is 2.2 volts. This causes their rather high specific characteristics which approach the specific characteristics of the STs storage batteries, particularly for the specific energy per unit of volume. Among the drawbacks of the lead-zinc cells are the complete inoperability at temperatures close to zero, and the significant gas release during use.

The lead-cadmium cells in terms of cost are significantly higher than the lead-zinc, but operate sufficiently well at a temperature of -30° centigrade. The voltage of the lead-cadmium cells is rather high, around 2 volts. The electrolyte of the lead-cadmium cells is sulphuric acid with a density of 1.30. This also determines their brief use in a filled state. The specific characteristics of the lead-cadmium cells are higher than for the lead storage batteries, but the stability of the discharge voltage makes it possible to use them in equipment requiring a smooth discharge performance. The strong release of gases during discharge is a drawback of the lead-cadmium cells.

A lead cell with perchloric acid as the positive electrode has lead dioxide applied to a copper screen which has been passivated by a metal resistant to the perchloric acid. The negative electrode is made from lead. As was mentioned above, perchloric acid is used as the electrolyte. This is a very aggressive chemical requiring extremely careful handling.

A merit of the lead cells with perchloric acid is effective operating at low temperatures. The batteries made up of KhS-15 cells, at a temperature of -40° centigrade, produced up to 90 percent of their nominal capacitance, while the temperature limit for the KhS cells reaches to -60° centigrade. For this the KhS cells have no equal. Among the drawbacks of this type of cell are the short service life in a filled state and the necessity of extremely careful handling of the electrolyte, perchloric acid, which causes severe burns if it gets on human skin, and is also capable of spontaneous combustion and explosion in combining with organic substances.

The voltaic cells with a solid electrolyte are among the reserve cells which, however, could scarcely be called wet cells. This type of cell has plates of sheet calcium or magnesium as the negative electrode. The positive electrode consists of tungsten oxide in a mixture with lead chromate applied on a nickel screen. The cell's electrolyte consists of a mixture of potassium chloride and lithium chloride, and at an ordinary

temperature is a solid crystalline mass. The cell is activated by heating the electrolyte to a temperature of 400-600° centigrade before changing to a molten state. At this temperature, the cell can deliver a very heavy current over a brief time interval. An example of a calcium cell with a solid electrolyte from a mixture of KCl and LiCl and having dimensions of 9 x 51 mm (diameter) and weighing 38 grams, in discharging with a 10-amp current, operated for five minutes with a voltage of 1.8 volts. Such cells in brief discharge systems develop a specific power of up to 380 watts per kilogram. A drawback of the cell, like the other reserve current sources, is the poor shelf life after activating the cell. The shelf life of the cells in a nonactivated condition is 10 years. Special thermite tablets located directly in the electrolyte serve as the sources of heat for bringing the electrolyte to a molten state.

Fuel Cells

The first models of fuel cells were developed by Grove in 1839. The operating principle of these cells consisted of the continuous oxidation of hydrogen on one of the platinum electrodes half submerged in the electrolyte. The end result of the chemical reaction between the oxygen and hydrogen was the formation of water with the simultaneous occurrence of an electromotive force, the amount of which reached one volt.

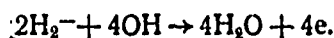
In 1876, the Engr-Lt P. N. Yablochkov obtained a patent for an "electromotive combustion cell" which was one of the variations of the hydrogen-oxygen cells. In 1890, he proposed an "autoaccumulator voltaic battery" with a very interesting patent formula which stated that the autoaccumulator was a "continuous action cell, the positive electrode of which was directly polarized, and an electric accumulator operable at one's wishes, by merely closing the circuit between the body accumulating the hydrogen and the body accumulating oxygen." In the Yablochkov fuel cell, lead was the hydrogen electrode and porous charcoal was the oxygen electrode. Metallic sodium was used as the fuel in this cell.

The importance of solving the problem of developing a fuel cell was that, in contrast to the chemical current sources, the operating life of which depends upon the quantity of active substances stored by the electrodes, the fuel cells can operate for as long a time as the substances necessary for their action are supplied. That is, the fuel sources of current can be classified as generators which are analogous in terms of their action, to the heat engines where fuel is burned for obtaining mechanical energy.

The capability of direct conversion of fuel energy into electrical energy is the most important feature of the fuel cells, since their theoretical efficiency can reach 100 percent, while the efficiency achieved in modern types of fuel cells is already 60-70 percent. Here it must be remembered that the efficiency of such engines as the steam or gas turbines does not exceed 40 percent, without even mentioning the internal combustion motors and the steam engines with an efficiency of 30 and 20 percent, respectively.

Moreover, the fuel cells are characterized by very high specific characteristics. For example, the amount of specific energy of an oxygen-hydrogen cell for long-term operating conditions can reach 1000 watts per hour per kilogram, while the best models of voltaic cells and storage batteries in terms of specific energy do not surpass 110-140 watts per hour per kilogram. Here if one considers that the fuel cells do not produce harmful substances, that they are noiseless and can operate for a long period of time, one can fully understand the interest shown in these sources of current.

The operating principle of a fuel cell consists in the fact that in passing hydrogen and oxygen through porous tubes which are located in a vessel with an alkaline electrolyte, the hydrogen atoms combine with the hydroxyl OH radical obtained as a result of the disintegration of the electrolyte into potassium ions and OH radicals. Here, water is formed and electrons are released:



At the same time, on the positive electrode the oxygen combines with the water and the hydroxyl OH radical is formed.

In principle, in a fuel cell, as the negative electrode it is possible to use not only hydrogen, but any hydrocarbon fuel such as methane, water gas, natural gas, carbon monoxide, and so forth. Oxygen or air as well as strong oxidants serve as the positive electrode.

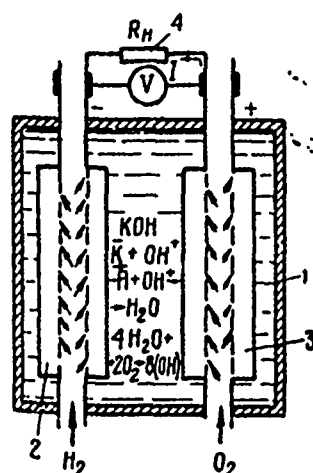


Figure 17. Operating principle of a fuel cell:
1 -- KOH electrolyte;
2 -- hydrogen negative electrode; 3 -- oxygen positive electrode; 4 -- load.

The operating principle of a fuel cell is shown in Figure 17. The electrons which accumulate on the pipe 2 which is the negative electrode are sent through the external circuit to the positive oxygen electrode 3, where they are captured by the oxygen. And the result of this an electric current begins to flow in the external circuit. Thus, the oxygen continuously replenishes the consumption of OH in the electrolyte, while the hydrogen maintains the necessary quantity of water in the electrolyte.

The chemical process occurring in a fuel cell is opposite to the process of the electrolytic decomposition of water where oxygen and hydrogen are formed in passing a current through acidified water.

At present, a large number of fuel cells have been developed. These differ in terms of operating principle and design. In accord with the classification used in electro-

chemistry, fuel cells can be divided into four basic groups: I -- low temperature cells with an operating temperature to 100° centigrade; II -- medium temperature cells from 100° to 300° centigrade; III -- high temperature cells from 300° to 1000° centigrade; IV -- regenerative or redox cells.

Among the low temperature cells are a number of hydrogen-oxygen cells with an alkaline electrolyte. In terms of operating principle, these cells virtually do not differ from the one shown in Figure 17. An important problem the solution to which determines the industrial production of such types of elements is the creation of a high-porous carbon electrode designed for high current densities and which is not softened by the electrolyte. Other types of low temperature cells have cermet porous electrodes, while the electrolyte saturates porous layers between the electrodes.

The portable generators developed by the General Electric firm for powering communications installations and field radar stations with a power of 200 watt have, as electrodes, platinum-plated metal grids applied to both sides of a plate from a special ionite which is the solid electrolyte. In the initial development, such ionite membranes made it possible to drain from the electrodes a current with a density of 20-30 milliamps per square centimeter, but recently it has been possible to develop membranes designed for a current drain of up to 200 milliamps per square centimeter.

A battery made up of such fuel cells was carried on the American Gemini space craft. The voltage of each of the cells comprising the battery was 0.8 volts. The power of the battery was two kilowatts with an efficiency of 60 percent. Liquid hydrogen was used as the fuel of the battery, while liquid oxygen was the oxidant. The water formed during use was drained off into a collector and could be used by the crew of the ship for drinking. The operating principle of the battery is shown in Figure 18. In the opinion of American specialists, such batteries can be successfully used on submarines of the antisub defense system.

Among the medium-temperature fuel cells is the well-known Bacon cell with porous electrodes, the design of which provides good ion conductivity between the electrode materials, the hydrogen and the oxygen, and the electrolyte, KOH, simultaneously preventing their mixing or displacement. A diagram for the operation of a medium-temperature Bacon cell is shown in Figure 19. The cell operates at a temperature of 200° centigrade. On this principle, the U.S. has developed fuel cells permitting a current drain with a density of up to 250 milliamps per square centimeter with a voltage of 0.92 volts. In a battery developed for the Apollo plans with a power of 3 kilowatts, as in the battery for the Gemini space ship, the water formed as a result of the electrochemical reaction can be used by the astronauts for drinking. The cooling of the battery is also liquid through a self-contained system using ethyleneglycol as the cooling agent. In the battery, a molten 85 percent KOH solution serves as the electrolyte.

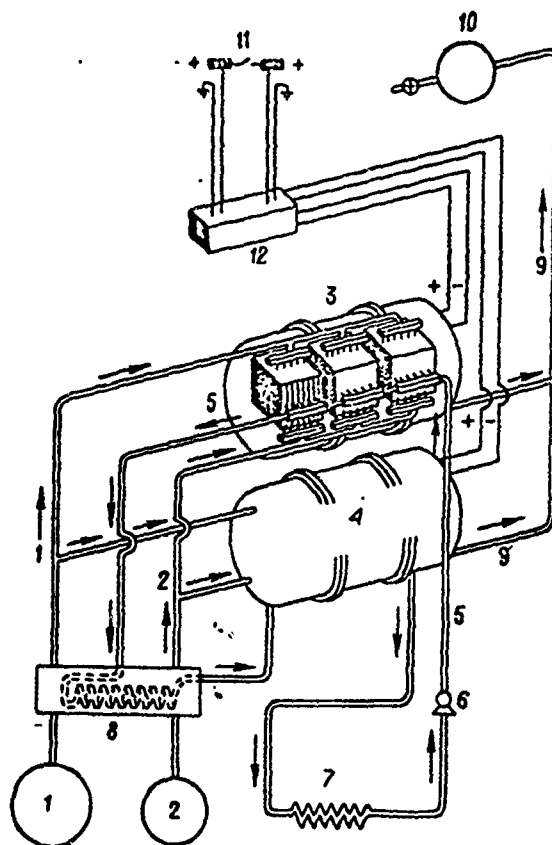


Figure 18. Diagram of the Gemini power unit:
 1 -- hydrogen; 2 -- oxygen; 3 -- battery of
 fuel cells (3 blocks) 4 -- reserve fuel cell
 battery; 5 -- cooling fluid; 6 -- pump; 7 --
 radiator; 8 -- heat exchanger for preliminary
 heating of active substances; 9 -- water;
 10 -- water collector; 11 -- output terminals;
 12 -- electric regulator.

In a battery manufactured in Sweden for submarines, instead of liquid hydrogen the storage of which poses certain technical difficulties, they have proposed using liquid ammonia which can be stored in thin-wall tanks.

In other low temperature fuel cells, they use such fuels as methanol, hydrazine and metallic sodium. Such batteries are being developed by various firms of Switzerland, West Germany and the U.S., for a power of from 10 watts to 3 kilowatts.

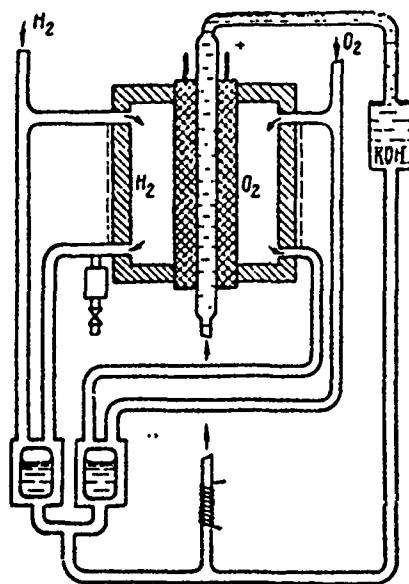


Figure 19. A hydrox fuel cell (Bacon cell).

In other types of batteries, where concentrated orthophosphorous acid is used as the electrolyte, it is possible to use as a fuel the vapors of alcohol and hydrocarbons. This greatly simplifies the design of the battery and its operation, since there is no necessity of pressure in supplying the fuel.

The high temperature fuel cells have attracted the attention of engineers and scientists by the fundamental possibility of using in them, as a fuel, not only hydrogen, but also hydrocarbons, carbon monoxide, methyl alcohol, natural gas, ammonia and even a solid fuel such as coke, charcoal and lampblack. In the high temperature cells, platinum, silver or zinc oxide are used as the electrodes. The electrolyte of this type of cell are either molten carbonates of alkaline metals, for example, Na_2CO_3 , or the so-called solid electrolyte composed of a baked mixture of cerium, zirconium or lanthanum, or ceramic porous plates saturated with the molten carbonates. In this type of cells, the purpose of the electrolyte is to provide good ion conductivity in the cathode-anode direction for the oxygen ions and to prevent electron conductivity.

The development of industrial models of high temperature fuel cells is complicated by a number of production and design difficulties, including the destruction of the cell electrodes, the decomposition of the electrolyte, the necessity of maintaining a high temperature in the operating chamber, and so forth.

In the models of fuel cells operating on a hydrocarbon fuel, it has been possible to achieve a high current density of around 150 milliamps per square centimeter with a service life of the cells of 1500 hours. Other cells operating on solid fuel have made it possible to drain a current with a density of up to 40 milliamps per square centimeter with a voltage of 0.7 volts. However, their service life is restricted to scores of hours. The high temperature cells can find application in equipment with limited service life, but their basic purpose is in the power production of the future, that is, direct conversion of solid fuel energy into electrical energy with a high efficiency.

The fourth group of fuel cells, the regenerative or redox cells, differs from the previously described in the ability to restore the active

substances consumed in the formation of electric current. The regeneration of active substances can be done by various methods, however chemical regeneration is of the greatest practical interest. Figure 20 shows a schematic diagram of the work of a redox cell in which reactions occur not related to a chemical change of the substance but merely altering the valence of the inert electrodes, for example, of tin or bromide.

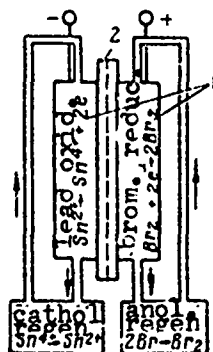


Figure 20. A redox cell: 1 -- carbon porous electrodes; 2 -- ion-exchange membrane.

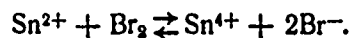
In the negative electrode of the cell, the reaction occurs for the reduction of the tetravalent tin into divalent. This reaction is related to the acquisition of two electrons by the electrode, as a result of which it becomes negatively charged. On the positive electrode, the reaction occurs of the oxidation of bromide into bivalent bromine by the air oxygen, and the electrode is positively charged.

Thus, a difference of potentials arises between the positive and negative electrodes of the redox cell. Elements with variable valence such as tin and bromine, in this model of a redox cell are the electrolytes. The tin which has been used to saturate the negative carbon porous electrode is called the catholyte, while the bromine in the positive also carbon electrode is the anolyte. Both electrodes are separated by an ion-exchange membrane which does not allow for the mixing of the electrolytes but does not obstruct the exchange of ions.

In this cell, the process of current formation is reduced to the reduction of an ion of a high-valence anolyte substance (in the given case, bromine) and oxidation of the catholyte (tin) ion in a low valent state to a high valent one.

Since the fuel (carbon monoxide) and oxidant (air oxygen) are substances which are consumed in the process of operating a regenerative cell, or maintaining the continuous operation of the cell, it is essential to regenerate the substances of the catholyte and anolyte. This, as was pointed out above, occurs by the reduction of the tin (catholyte) by the fuel and the oxidation of the bromine (anolyte) by the oxygen.

The total current formation reaction (and regeneration in the reverse direction) in the cell can be represented in the following manner:



Since the combustion of the carbon monoxide and its conversion into carbon dioxide CO_2 lead to the occurrence of an emf of 1.02 volts, the substances used in the catholyte and anolyte should also coincide with the

emf in terms of their electrode potentials. In the tin-bromide system, a change in the tin valence in the catholyte produces 0.15 volts, and 1.05 volts in the bromide. The total emf $E = E^+ - E^- = 1.07 - (-0.15) = 1.22$ volts, that is, it approximately coincides.

The redox cells operate at a normal temperature, and this is a positive feature for them. Moreover, the heat produced by them can be used in the cell itself for providing the regeneration process. In other types of fuel cells, this requires the supply of additional heat which sometimes surpasses the useful energy of the electric current.

The fuel cells, along with the positive features inherent to them such as high efficiency, noiseless operation, absence of harmful substances during use and a relatively long service life, also have shortcomings. These are: the necessity of using explosion-proof mixtures, the large sizes of the tanks or storing the fuel and oxidants, the large dimensions of the entire unit including the cooling system, and so forth.

The use of fuel cells is limited to the powering of medium and large-capacity equipment of hundreds of watts up to scores and hundreds of kilowatts. Here the power time should be sufficiently long. Then the specific characteristics of the fuel cells become incommensurable with the conventional chemical current sources, the specific energy of which does not exceed 200 kilowatts per hour per kilogram, while the specific energy of long-acting fuel cells obviously will not be restricted to 1000 kilowatts per hour of kilograms.

The use of fuel cells in an electric car is very probable, since the experiments conducted by designers in the U.S. in this direction have provided positive results.

Biological Cells

Biological cells are classified as chemical sources of current, since the occurrence of an electromotive force in them is a consequence of oxidation-reduction processes inherent to the chemical sources of current.

As was pointed out above, for obtaining an electric current, it is essential that the cell have a fuel (hydrogen or other gaseous fuels) and an oxidant (oxygen). In the biological cells, the fuel and the oxidant can be obtained from various organic substances in introducing into them the corresponding bacterial flora which causes fermentation processes, in the process of which hydrogen and oxygen are produced.

The process of obtaining an electric current in a biological cell, where bacteria are used for converting an organic fuel into hydrogen and oxygen, is called an indirect method in contrast to the direct method where the bacteria themselves participate in the current-forming process. The direct method is the most prospective, since it does not provide for the use of organic substances requiring their continuous replenishment during use.

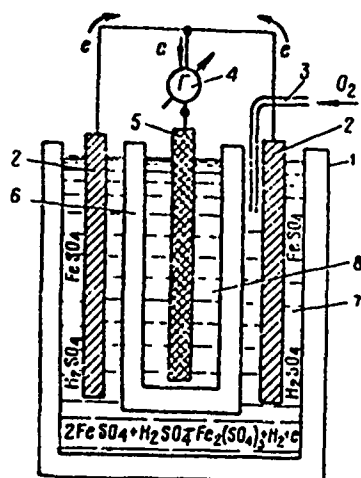


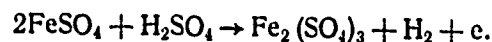
Figure 21. A biological cell:
 1 -- container of cell;
 2 -- passive cylindrical electrode; 3 -- tube for delivery of air; 4 -- galvanometer; 5 -- collector electrode; 6 -- vessel with porous walls; 7 -- electrolyte of sulphuric acid and iron vitriol; 8 -- solution containing bacteria flora.

the bacteria of which possess the capability to feed on electrons with the formation of water molecules by the addition of oxygen which also is supplied to the solution. As a result of the continuous destruction of the received electrons by the bacteria, a current flows in the circuit, the amount of which is determined by the absorptive capacity of the bacteria.

Many research organizations are engaged in developing current sources which use biological processes. For example, the foreign press has announced a developed biological current source in which as the bacterial flora they use a pulp-like mass of bananas, and a solution of inorganic salts is used as the electrolyte. This source of current, according to information in the press, over a period of 24 hours produces a current of 4.92 amps with a voltage of 0.76 volts. In this cell the bananas can be replaced by a watermelon, grapes or virtually any fruit. It is asserted that such a generator, after improvement, can produce direct-current energy with a power up a kilowatt.

The operating principle of a biological source of current with the immediate participation of bacteria in the current-forming process is shown in Figure 21. Here, in a vessel with a weak sulphuric acid solution with a certain quantity of ferriferous sulfate, there is a passive electrode from platinum or carbon. In the same vessel there is another vessel 6 from a porous material in which the same electrode is placed. The internal vessel contains an aqueous solution with a special type of bacteria, with oxygen or air being supplied to the vessel.

With the interaction of the weak sulphuric acid with the iron vitriol, the bivalent iron is converted into trivalent, and this conversion is accompanied by the loss of one valence electron:



The released electron through the passive electrode which is the electron collector and through the external circuit, is sent to the other passive electrode in the biological solution,

Another announcement points to the possibility of using bacteria for depolarization in the chemical sources of current. For example, in a battery with a magnesium anode and seawater as the electrolyte, it has been proposed that hydrogen-consuming bacteria be used for reducing the cathode polarization.

It has also been proposed that in the fuel cells using hydrogen and oxygen and active materials they employ bacteria which consumes respectively O_2 or H_2 on one electrode, and on the other bacteria producing O_2 or H_2 . It has also been recommended that colonies of the corresponding bacteria be used for cathode depolarization in cells with an iron cathode.

Since the biological current sources have just begun to be developed, at present it is difficult to analyze their characteristics or indicate the possible areas of use. However, the use of bacteria for providing certain processes which are secondary in current formation is already becoming a real thing.

As for the biological cells themselves, it is felt that they can be developed and used as reserve current sources operating as back-ups for the chemical current sources in regions where sources of industrial electric power are absent, or in specific equipment.

I. Storage Batteries

Cadmium-Nickel (KN) Sealed Storage Batteries

Recently, the users of current sources have become interested in the small-sized storage batteries of the sealed type which are cylindrical, circular and rectangular, and in the operating process do not require the replacement or addition of electrolyte and can operate in any position. Modern portable equipment and lighting installations require such sources of current. As a consequence of this, the sealed KN storage batteries are finding wider and wider use in radio broadcasting receivers, tape recorders, hearing aids, flashlights and as an illuminant for optical sights.

At present, Soviet industry produces three basic types of KN storage batteries of the sealed model: circular, cylindrical and storage batteries of the KNG type.

Circular Cadmium-Nickel Storage Batteries

This type of storage battery has gained widest use as a consequence of the cylindrical shape which is very convenient in joining into batteries, where the electrical connection can be provided by the mechanical compression of individual storage cells.

Soviet industry produces the D-06, D-0.1 and D-0.25 storage cells and the 2-2D-0.1 and 7D-0.1 storage batteries. The basic characteristics of the circular storage cells and batteries are given in Table 14.

Table 14
Sealed Circular Cadmium-Nickel Cells and Batteries

Type of cell (battery)	Voltage, V.	Capacitance, amp-hrs.	Discharge current, ma	Voltage at end of discharge, V	Charge current, ma	Charging time, hrs	Service life, cycles	Shelf life, years	Dimensions mm		Weight, g.
									dia.	height	
Storage cells											
1-0.06	1.25	0.06	6	1.0	6	15	150	2	15.6	6.4	4
1-0.1	1.25	0.1	10	1.0	12	15	150	1.5	20.1	6.9	7
1-0.25	1.25	0.25	25	1.0	20	19	200	1.5	27.2	10.3	16
Batteries											
2x21-0.1	2.50	0.20	60	2.0	24	15	70	1.5	23.2	38.0	36
21-0.25	2.5	0.25	25	2.0	20	19	150	1.5	27.2	22.5	33
21-0.1	8.75	0.10	10	7.0	12	15	150	1.5	24.1	62.2	60
101-0.25	12.50	0.05	50	10.0	20	19	—	—	82X109X10.5		200

The design of the cells and batteries is shown in Figure 22.

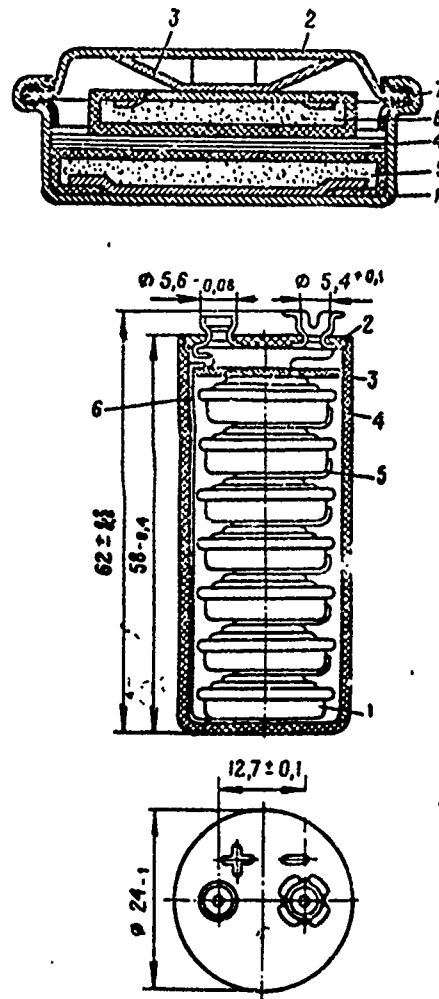


Figure 22. Design of circular sealed storage cells and batteries:

Above -- cross-section of a circular storage cell:

1 -- housing; 2 -- top of housing; 3 -- spring; 4 -- separator; 5 -- positive electrode; 6 -- negative electrode; 7 -- insulating gasket; below -- the 7D-0.1 storage battery; 1 -- the D-0.1 storage cell; 2 -- top; 3 -- insulating gasket; 4 -- housing; 5 -- nickel lobe; 6 -- nickel strip.

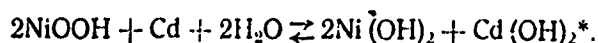
The circular storage cell consists of a housing 1, in which the positive 5 and negative 6 electrodes are located separated by a separator gasket 4. The entire block is pressed to the housing by a cross-shaped brace spring 3. The top of the housing 2 has been rolled with the housing

1 across an insulating gasket 7. The storage cell contains the minimally necessary quantity of electrolyte and this causes its low internal resistance.

Since the positive electrode of the storage cell 5 is electrically in contact with the housing, the latter has a positive polarity "+" for all types of circular storage batteries.

The chemical processes occurring in the sealed KN storage batteries, in discharging and charging, are analogous to the processes in the conventional KN storage batteries, namely:

The electrolyte in the circular storage batteries, as in the other alkaline storage batteries, is merely the carrier of the oxygen or the OH ions from the positive plate to the negative one, and does not participate in the chemical current-forming processes.



As is known, in charging the KN storage batteries, oxygen and hydrogen are released, and as a consequence of this the KN storage batteries are equipped with ventilating plugs. In what manner is it possible to avoid the release of gas in the sealed storage batteries?

In the circular storage batteries, the process of gas formation is restricted to only oxygen, since the mass of the negative electrode for these storage batteries is always in surplus in relationship to the positive electrode. This excludes the possibility of the production of hydrogen on the negative at the end of charging, since this electrode is always undercharged.

At the same time, the oxygen released on the positive nickel-oxide electrode, due to the extremely limited quantity of the electrolyte in the storage battery, is not able to be released in a free state and is continuously absorbed by the negative cadmium electrode, the mass of which, as was mentioned above, is greater than the mass of the positive electrode. Thus, the circular cadmium-nickel storage batteries are completely sealed both in charging and discharging.

The design of the circular sealed KN storage batteries allows for an overcharging on the order of 50 percent in time. These storage batteries can also be operated under continuous charging conditions. This can be used with the combined powering of equipment from solar current sources in a buffer with the circular KN storage batteries.

* Here and in following formulas, the discharge reaction is shown from left to right, and the charge reaction from right to left.

In recent years, significant changes have occurred in the production of the circular storage batteries. As a result of these changes, the service life and shelf life of the storage batteries have been substantially increased, and such operating characteristics as use at the temperature below zero have been improved.

While 5 or 6 years ago the manufacturing plants guaranteed the operation of the circular KN storage batteries only within limits of from $+5^{\circ}$ to $+35^{\circ}$, while now (state standard 11258-65), the lower temperature limit for the use of the circular storage batteries has been brought down to -10° . Here, the capacitance of the circular storage batteries at a temperature of -10° should not be reduced by more than 40 percent of the rated.

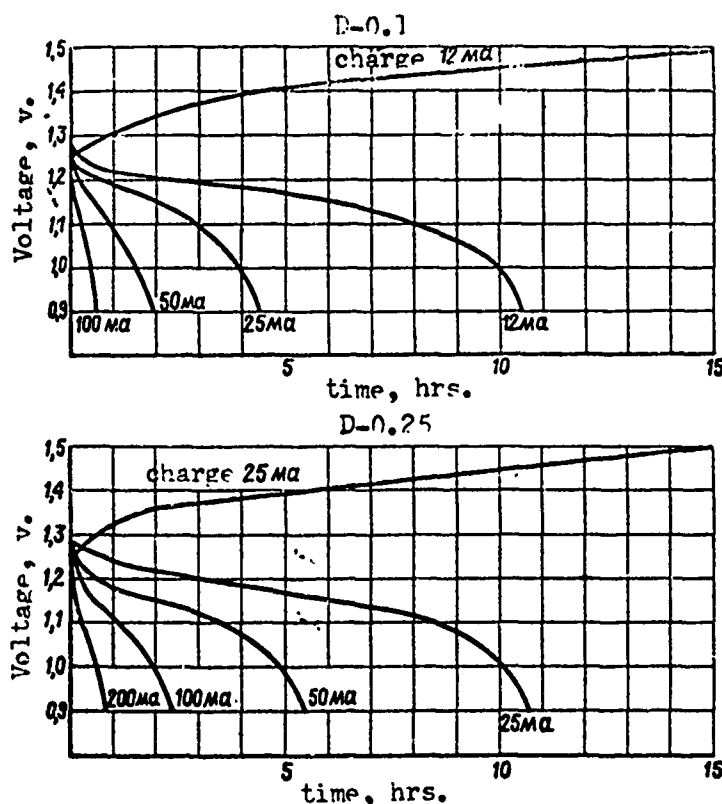


Figure 23. Charge and discharge characteristics of the D-0.1 and D-0.25 storage batteries at a temperature of $+18^{\circ}$ centigrade.

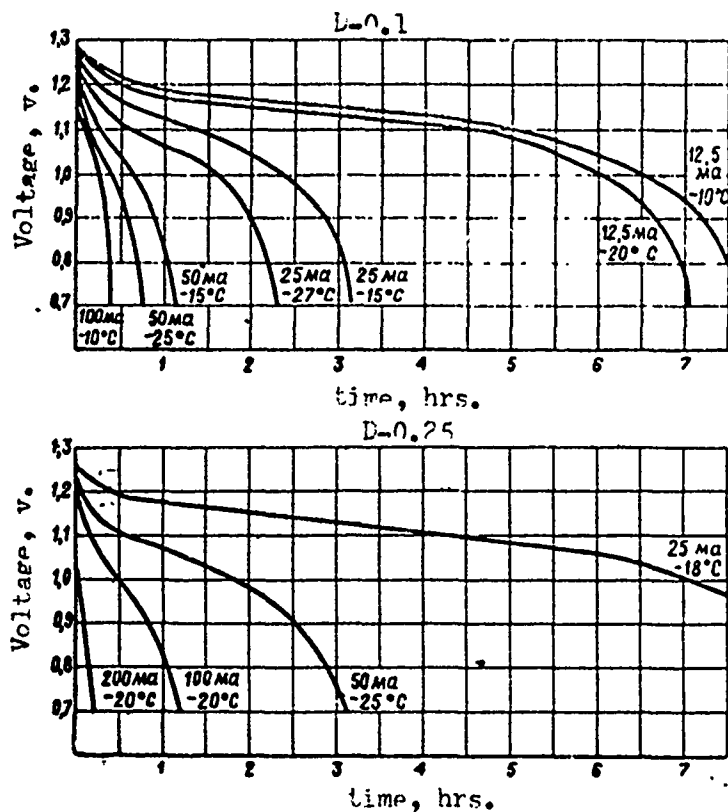


Figure 24. Discharge characteristics of the circular storage batteries with a negative temperature.

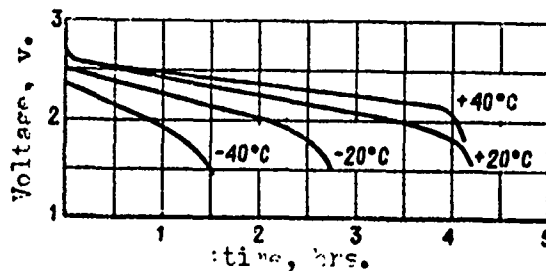


Figure 25. Discharge curves of the 2x2D-0.1 battery with a constant resistance of 3.6 ohms.

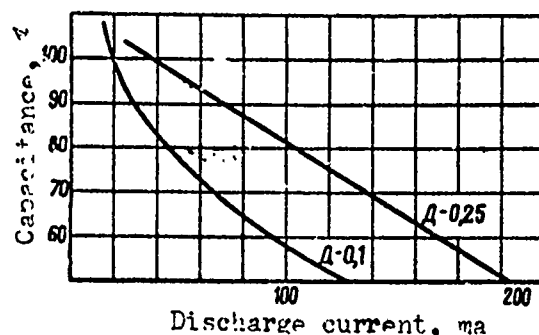


Figure 26. Characteristics for the dependency of capacitance of circular storage batteries upon discharge current (with a discharge to 1.0 volts).

The graphs of figures 23-25 show the discharge characteristics of the D-0.1 and D-0.25 storage cells and the 2-D-0.1 storage battery at a normal temperature and a temperature below zero. From these graphs it follows that the actual efficient operation of the circular storage batteries with a negative temperature is significantly higher than the one guaranteed by the state standards. This shows a certain production reserve in the capacitance of the storage batteries. From the discharge curves it follows that the circular storage batteries at a temperature of -20° are capable of producing up to 50 percent of their rated capacitance. This makes it possible to significantly broaden the limits of their use in mobile equipment.

Like the other KN storage batteries, the circular storage batteries produce a reduced capacitance with forced discharge conditions (Figure 26).

In considering that the presently produced circular storage batteries have sufficiently stable capacitance characteristics, in a number of instances it is possible to use not only the series but also the parallel connection of the storage cells into batteries, and has been done, for example, in the 2x2D-0.1 battery. This battery, with a rated voltage of 2.5 volts, has a capacitance of 0.2 arps per hour. This makes it possible to use it as a source of power for miniature incandescent lights. At a normal temperature, the burning time of such a light from a 2x2D-0.1 battery is around four hours, and around one hour at a temperature of -40° .

The circular storage batteries which have been discharged at a temperature below zero, after thawing and a normal room temperature, are capable of producing additional capacitance. The ability to produce additional capacitance after thawing is explained by the increase in the mobility of the ions with a rise in temperature.

During the service life, the capacitance of the circular storage battery declines, and this is specially stipulated by the plant technical

conditions. After one-half of the service life, the capacitance of the batteries can drop by 20 percent below the rated. After 30 days of storage in a charged state, the self-discharge of the circular storage batteries is 30-35 percent.

One particular feature of operating the circular sealed storage batteries is the necessity of charging them with weak currents on the order of 10 percent of the amount of the rated capacitance, since accelerated charging conditions do not provide for the prompt absorption of the oxygen by the negative electrode. This can lead to the swelling of the storage battery and a breaking of its seals.

The use of circular storage batteries is basically restricted to carried "pocket-sized" equipment. The D-0.06 storage batteries are widely used in various types of hearing aids, while the D-0.01 storage batteries are used in small-sized radio receivers where the discharge current does not exceed 20 milliamps, as well as in lighting systems in the form of the 2x21-0.1 battery where the discharge current is 60 milliamps. The D-0.25 storage batteries are used in equipment where the discharge current reaches 100-150 milliamps.

Since the sealed storage batteries are operated under conditions of periodic connecting, Figure 27 gives the discharge characteristics of the storage cells and batteries with interrupted connecting. From this it follows that under interrupted discharge conditions, the sealed storage batteries, in discharging by a current which exceeds the rated discharge current by 400-500 percent, are capable of producing the rated capacitance.

Figure 28 shows types of circular storage batteries and cells as produced by our industry.

Cylindrical Sealed Cadmium-Nickel Storage Batteries

The cylindrical storage batteries differ from the circular ones not only in shape, but also in terms of the degree of hermeticity. They have a comparatively fixed corrugated cover which is capable of withstanding the pressure of several score atmospheres.

The electrodes of the cylindrical storage batteries can be both lamel as well as lamelless. In the TsNK [cylindrical nickel cadmium] storage batteries, lamel electrodes are used. The electrolyte, as in the circular storage batteries, is located in the pores of the plate and in the separation, and is virtually absent in a free state.

The design of a cylindrical sealed KN storage battery, the TsNK-0.45, is shown in Figure 29.

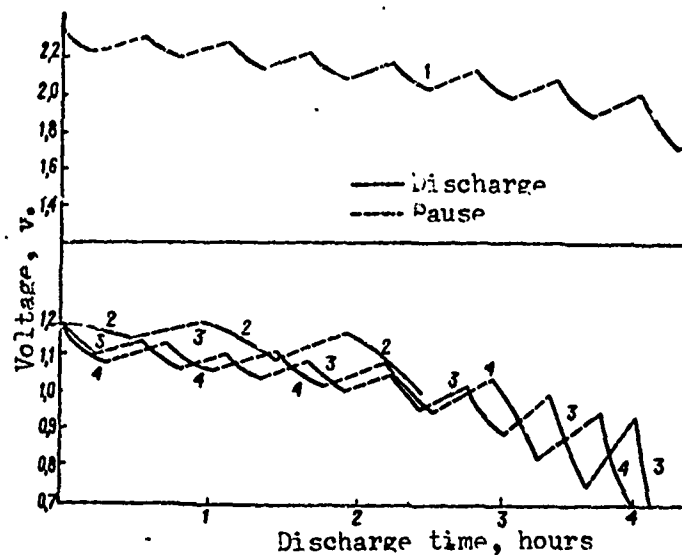


Figure 27. Characteristics of field storage batteries under periodic discharge conditions:

1 -- 2x2D-0.1 battery with a current of 60 milliamps at a temperature of -20° centigrade; 2 -- D-0.06 storage cell with a 30 milliamp current at a temperature of $+20^{\circ}$ centigrade; 3 -- TsNK-0.45 storage battery with a 100 milliamp current at -25° centigrade; 4 -- D-0.01 storage cell with a 30-milliamp current at -25° centigrade.

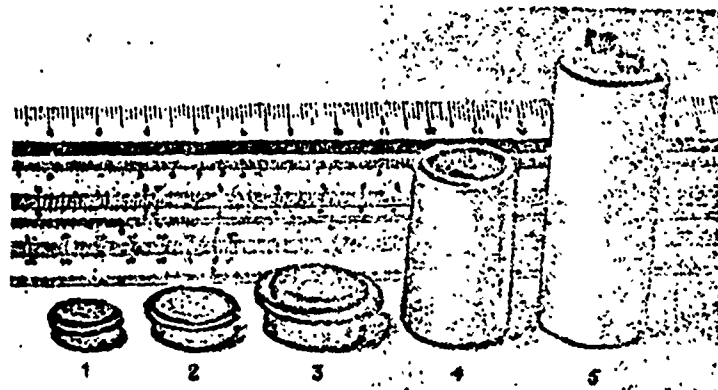


Figure 28. Examples of the circular sealed KN storage batteries and cells:

1 -- D-0.06; 2 -- D-0.1; 3 -- D-0.25; 4 -- 2x2D-0.1; 5 -- 7D-0.1

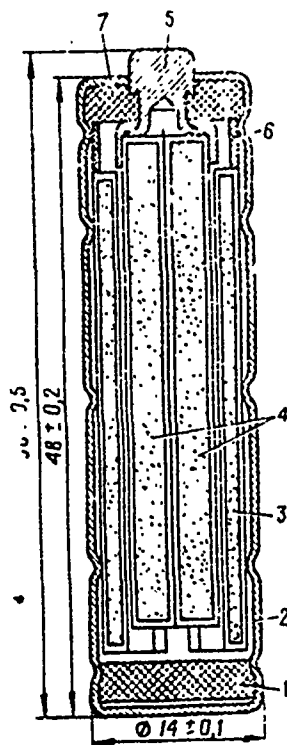


Figure 29. The TsNK-0.45 storage battery

1 -- bottom; 2 -- housing of vessel; 3 -- negative plate; 4 -- block of positive electrodes with separation; 5 -- positive lead; 6 -- ring; 7 -- top.

battery and the conditions for its use. Storage batteries operating under long discharge conditions have an increased service life.

Table 15 gives the basic characteristics of the cylindrical storage batteries produced by Soviet industry.

The cylindrical KN storage batteries are used for powering small-sized carried equipment such as radio receivers, tape recorders, communications equipment, geophysical equipment, and so forth. The relatively low cost, the long service life, the good resistance to the effect of impact loads and operational simplicity cause their wide use.

The TsNK-0.45 cylindrical storage battery has gained the widest use, and its charge and discharge characteristics are given in Figure 30.

Since in a cylindrical storage battery the negative electrode 3 has an electrical contact with the housing, the latter has a negative polarity "−" in contrast to the circular storage batteries where the housing has a "+." The terminal of the positive electrode has been pressed in the plastic top, and from it run the current leads in the form of strips for connection to a circuit.

The design of the cylindrical storage batteries allows a 100 percent capacitance recharging, and provides the possibility of employing forced discharge conditions without breaking the sealing. As a consequence of this, the cylindrical storage batteries are used in equipment requiring minute discharges of heavy current.

The operating temperature range of the cylindrical storage batteries lies within limits of from +35° to +5° centigrade (according to the technical conditions of the manufacturing plant). However, the actual limit of the temperature range reaches minus 10-15° centigrade.

The service life of the cylindrical storage batteries lies within limits of from 100 to 300 cycles depending upon the type of storage battery and the conditions for its use.

Table 15

Cylindrical Cadmium-Nickel Storage Batteries

Type of cell, battery	Emf., V.	Cap., a-hr	Discharge current, ma	Voltage at end of dis- charge, V	Charging current, ma	Charging time, hrs.	Dimensions, mm.			Weight, g
							length	width, diam.	height	
Storage cells										
TSBK										
ЦНК-0.2	1.36	0.20	20	1.0	20	15	—	Φ16	24.5	15.0
ЦНК-0.45	1.36	0.45	45	1.0	45	15	—	Φ14	50.0	23.0
ЦНК-0.85	1.36	0.85	85	1.0	85	15	—	Φ14	96.0	41.0
Batteries										
3ЦНК-0.2	4.08	0.20	40	3.0	20	15	—	Φ16	74.0	40.0
5ЦНК-0.2	6.80	0.20	100	5.0	20	15	87.0	24.0	27.0	117.0
11ЦНК-0.45	14.96	0.45	90	11.0	45	15	112.0	39.0	57.0	350.0

Figure 31 gives the characteristics for the capacitance dependency of this storage battery upon the discharge conditions, and Figure 32 shows the temperature dependency.

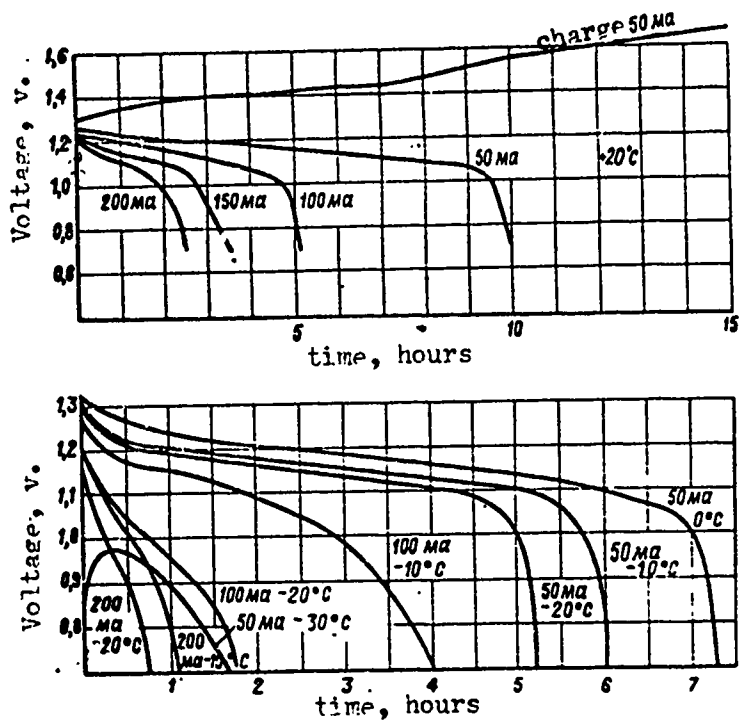


Figure 30. Charge and discharge characteristics of the TsNK-0.45 storage battery.

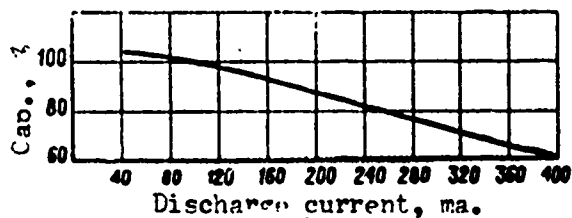


Figure 31. Characteristics of the capacitance dependency of the TsNK-0.45 storage battery upon discharge current (with a discharge to 1.0 volts at a temperature of +20° centigrade).

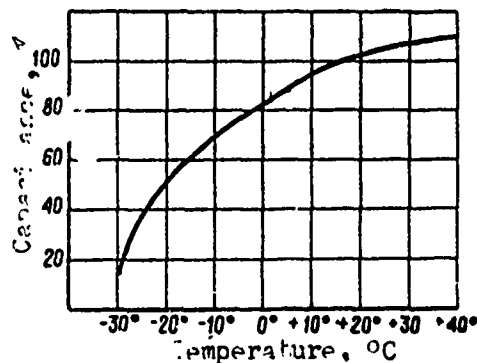


Figure 32. Characteristics of the capacitance dependency of the TsNK-0.45 storage battery upon temperature with 10-hour discharge conditions (discharge to 0.7 volts).

The 4TsNK-0.45 batteries provide very good results in equipment designed to be powered by a KBS-0.5 battery. For several years the author has used in a Sport-3 movie camera and an Atmosfera radio, batteries made up of 4 and 8 TsNK-0.45 storage cells enclosed in a housing of organic glass.

The cadmium-nickel sealed circular and cylindrical batteries have been widely used abroad. These batteries are manufactured in a majority of the European nations as well as in the U.S. and Japan.

KNG Sealed Cadmium-Nickel Storage Batteries

The sealed cadmium-nickel storage batteries (KNG) differ from the cadmium-nickel sealed circular and cylindrical storage batteries both in design as well as in the principle of reducing the pressure to provide hermeticity.

While in the cylindrical and circular storage batteries the absorption of oxygen by the cadmium electrode during charging and the absence of the emission of free oxygen at the end of the charge are provided by the surplus capacitance of the negative electrode, in the storage batteries of KNG type, an additional carbon electrode has been used connected to the negative cadmium electrode. The purpose of this second electrode is to absorb the oxygen in the charge process, as well as to draw off electrolyte and equalize the potential at the top of the plate. As a whole this helps the fuller regaining of charge capacitance and the normalization of pressure within the battery vessel. The design of a storage battery of the KNG type is shown in Figure 33.

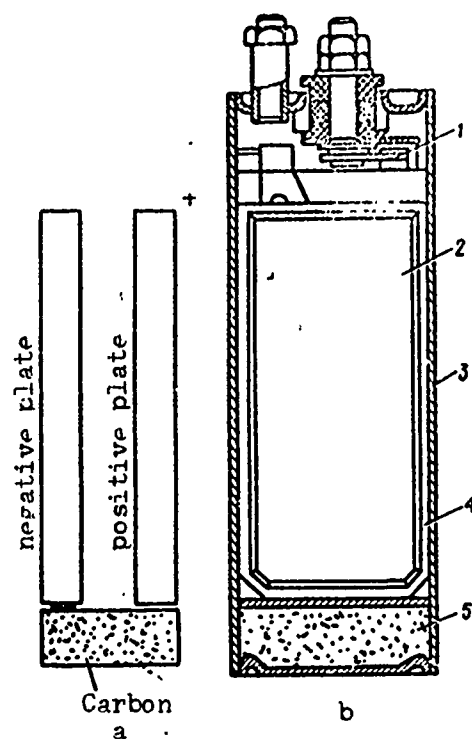


Figure 33. Diagram (a) and design (b) of sealed cadmium-nickel storage battery with carbon electrode; 1 -- block of positive plates; 2 -- block of negative plates; 3 -- vessel; 4 -- separator gasket; 5 -- carbon electrode.

Depending upon the discharge conditions, industry produces three types of KNG storage batteries; KNG-d for long-discharge conditions, KNG-s for medium conditions and KNG-k for short conditions.

The basic characteristics of certain types of KNG storage batteries and cells are given in Table 16.

A particular feature of operating the KNG batteries is the necessity of careful control of capacitance in charging. Since surplus capacitance in charging the KNG battery, is converted into heat, systematic overcharging reduce the capacitance of the storage battery and shorten its service life. The normal charging of the KNG storage battery should provide for the obtaining of a capacitance, in charging, on the order of 110-120 percent of the actual capacitance of the given storage battery. The tolerable overcharging should not exceed 50 percent of the actual capacitance of the storage battery.

Table 16
Sealed Rectangular Cadmium-Nickel Cells and Batteries

1) Тип аккумулятора (батарея)	2) Напряжение, В	3) Емкость, А·ч	4) Ток разряда (ном.), А	5) Конечное напряжение, В	6) Характеристики серии		7) Срок службы, лет	8) Срок хранения, лет	9) Габариты, мм			13) Вес, кг	
					Время зарядки, ч	Ток зарядки, А			Длина мм	Ширина мм	Высота, мм		
Cells													
KNG													
KHG-0.7	1.26	0.7	0.07	1.0	15	0.07	—	—	25	12	41	0.038	
KHG-3.5D	1.26	3.5	0.25	1.0	15	0.35	800	3 г	45	20	70	0.20	
KHG-7.5	1.26	7.5	0.75	1.0	15	0.75	800	3 г	45	42	70	0.50	
KHG-10D	1.26	10	1.0	1.0	15	1.0	800	3 г	45	30	146	0.55	
KHG-15CS	1.26	15	5.0	1.0	15	1.5	800	3 г	46	45	146	0.83	
KHG-30C	1.26	30	9.0	1.0	15	3.0	800	3 г	87	41	171	1.50	
KHG-30CA	1.26	30	9.0	1.0	15	3.0	800	3 г	87	41	171	1.50	
KHG-50C	1.26	50	15.0	1.0	15	5.0	800	3 г	88	73	171	2.70	
Batteries													
3KHG-10D	3.75	10.5	1.0	1.0	13-15	1.0	600	ок. 2	90	45	145	1.80	

Key:

1. Type of cell (battery)
2. Voltage, V.
3. Capacity, amp-hr.
4. Discharge current (rated)
amp
5. End voltage, V.
6. Charge characteristics
7. Service life, cycles
8. Shelf life, years
9. Dimensions, mm
10. length
11. width
12. height
13. Weight, kg
14. Charge time, hours
15. Charge current, amp.

The normal temperature which provides the best charging conditions for the batteries of the KNG type is a temperature of from $+15^{\circ}$ to $+20^{\circ}$ centigrade.

In connecting the KNG storage cells into batteries, it is essential to choose the storage cells in terms of capacitance in order to avoid deep discharges of the storage cells with a somewhat reduced capacitance and the related possibility of the polarity reversal and ruining of the cells. The storage cells are selected for capacitance discrepancies within limits of 3-4 percent. In determining the capacitance of the storage cells, they are discharged to a voltage of one volt.

In the process of operating the batteries made up from storage cells of the KNG type, it is essential to make certain that the final voltage of the battery is not lower than one volt on each storage cell.

With protracted storage of the KNG storage batteries, the first charge must be made until 100 percent of capacitance is reached, and only in subsequent charges should the storage batteries be given 120-130 percent of their actual capacitance.

The discharge characteristics of the KNG storage cells are given in Figure 34. The discharge conditions (indicated in Table 16) recommended for operating the KNG storage batteries, when the discharge current does not exceed 0.1 of the battery's capacitance, provide protracted operation without destroying the hermeticity of the storage batteries. The dependency of the capacitance produced by the batteries in discharging upon the amount of discharge current is shown in Figure 35.

The KNG storage batteries can work in a temperature range of from $+40^{\circ}$ to 0° centigrade, however, with negative temperatures, the capacitance of the KNG storage batteries, like the other chemical current sources, declines. The capacitance dependency of the KNG storage batteries upon temperature is given in Figure 36.

The KNG storage batteries can be stored at a temperature of from -40° to $+40^{\circ}$ centigrade. Self-discharge, in storing under normal conditions ($+20^{\circ}$ centigrade), is 30-35 percent per month. At a temperature below zero, the self-discharge of KNG storage batteries declines sharply. After protracted storage in a charged state, the KNG storage batteries produce a reduced capacitance, and here the average amount of discharge voltage also falls. After normal charging, the KNG storage batteries completely restore their characteristics.

The KNG storage batteries possess good mechanical properties. They operate with vibration loads and an acceleration to 10 g and a vibration frequency of from 10 to 2000 hertz, and tolerate impact loads with an acceleration up to 400 g. The KNG storage batteries do not stand as well the impact loads aimed along the plates.

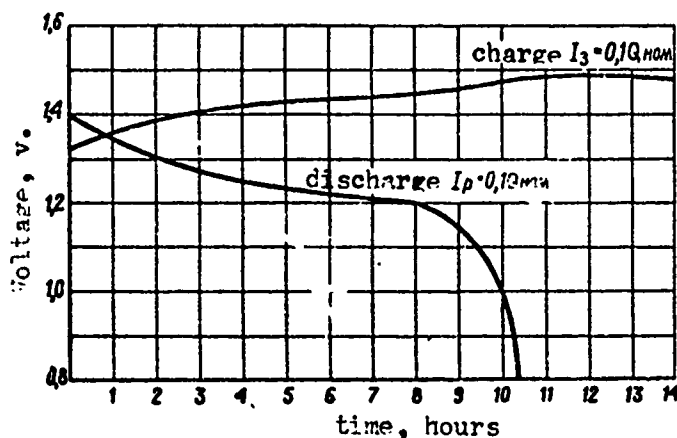


Figure 34. Discharge and charge characteristics of a KNG storage battery at a temperature of +40° centigrade.

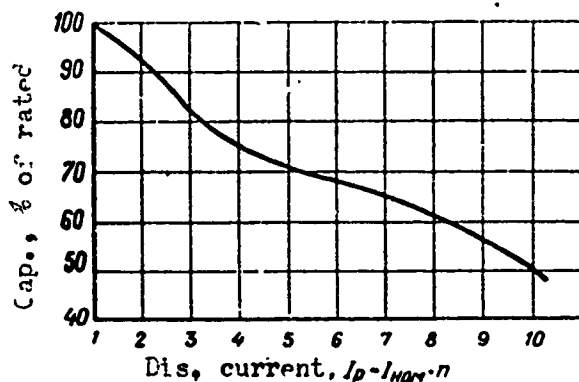


Figure 35. Graph of the dependency of capacitance produced in discharge by a KNG storage battery upon discharge current.

As was pointed out above, the KNG storage batteries should be charged with a current, the amount of which is 0.1 of the rated capacitance value of the storage battery. When necessary, it is possible to use an accelerated charging system in two stages: the first with a current of 0.2-0.5 of the normal capacitance value until reaching 80 percent of rated capacitance, and the second, with a current of 0.1 of the rated capacitance until reaching a total capacitance of 120-150 percent.

However, the accelerated charging system requires careful supervision in the charging process. This is not always possible under the conditions of using the storage batteries in autonomous systems.

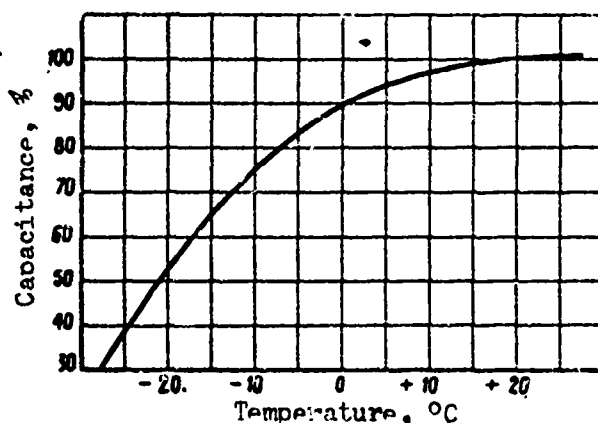


Figure 36. Dependency of capacitance produced by KNG storage battery upon temperature.

For autonomous systems where use is monitored by automation, a sealed KNG-50SA storage battery is produced (Figure 37) with an automatic end of charge indicator, the design of which is shown in Figure 38.

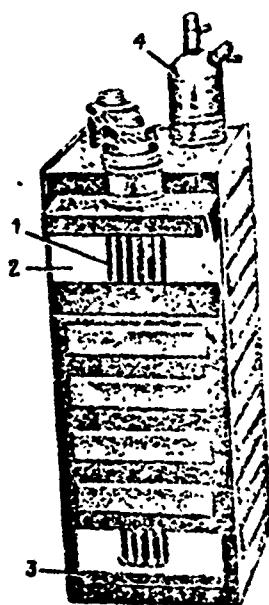


Figure 37. An KNG-50SA storage battery an automatic end of charge indicator;

1 -- cermet plates; 2 -- separator fabric; 3 -- layer of activated charcoal; 4 -- automatic end of charge indicator.

The end of charge indicator is a bellows pressure pickup which has been built into the battery's housing. Here the external surface of the bellows is under the pressure within the battery, while the internal surface is in contact with the atmosphere. When the battery has reached charged capacitance providing for a normal output of energy, and this is usually accompanied by a sharp pressure shift at the end of charging, the bellows is compressed, and the contact terminals 5 and 6 are closed. This causes a signal to be sent to the device controlling the charging.

The end of charge indicator makes it possible to charge the KNG-30SA and KNG-50SA storage batteries with heavy current over a short time interval. This very substantially broadens the area of use of the sealed storage batteries. The maximum charge current for a KNG-50SA storage battery with an end of charge indicator is 20 amps.

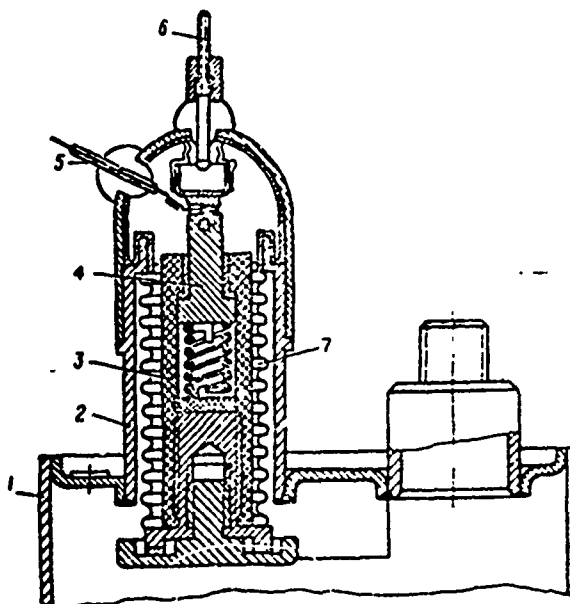


Figure 38. The automatic end of charge indicator:
 1 -- housing of storage battery; 2 -- indicator cup;
 3 -- insulating cup; 4 -- contact stem; 5 -- contact
 terminal; 6 -- contact core; 7 -- bellows.

Lamelless Cadmium-Nickel Storage Batteries

The widely found cadmium-nickel and iron-nickel storage batteries have low specific characteristics, and most importantly, poor efficiency at low temperatures. These drawbacks have impeded the use of the KN [cadmium-nickel] and ZhN [iron-nickel] storage batteries in portable equipment and instruments designed for use in the north. The KN and ZhN storage batteries are called lamel batteries, since their active materials are packed in perforated strips or lamels from which the plates are assembled (Figure 39). The lamels have openings (perforations), the dimensions of which do not exceed the size of the grains of active materials (in order to exclude the possibility of the falling out or washing out of the active materials and to provide, simultaneously, a maximum contact surface with the electrolyte).

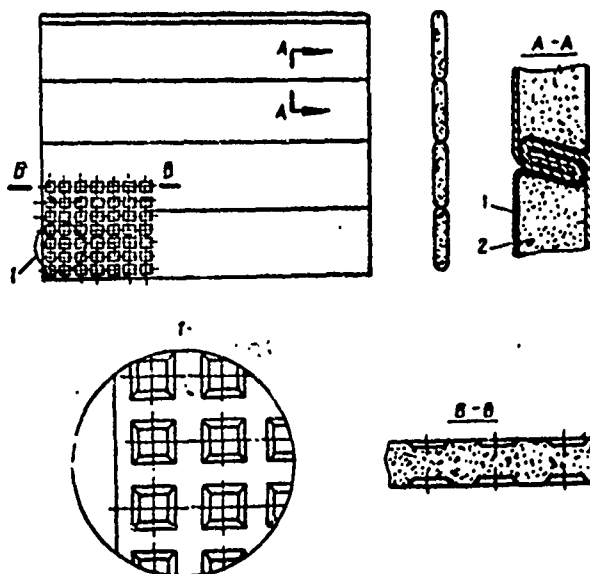


Figure 39. A lamel plate
1 -- lamel strip; 2 -- active mass

The first attempts to improve the specific characteristics of the KN and ZhN lamel storage batteries were undertaken in the direction of changing the design and production methods. The increase of the active surface of the plates by altering the shape and dimension of the openings did not produce any tangible results. A new design of plates and new manufacturing methods were more successful. As a result of this, a more advanced type of cadmium-nickel storage battery appeared which was called lamelless from the design of the plates.

Instead of a lamel plate, the new storage battery designed by M. S. Tsygankov, A. G. Sitnikov, N. A. Shutova and others used a cermet plate consisting of a frame with a powder pressed on it made from nickel carbonyl in a mixture with ammonium carbonate. After pressing the plates are fired in a hydrogen furnace at a temperature of 900°. Here the ammonium carbonate is evaporated out of the active mass, creating a high porosity (up to 30 percent). Then the plates are saturated, and as a result of this a plate saturated in a solution of nickel nitrate acquires the properties of a positive electrode, while the plates saturated in a solution of cadmium chloride becomes the negative electrode.

Thus, the plates of a lamelless storage battery are manufactured according to a uniform method, and their separation into positive and negative is made only at the final stage of saturation.

The high porosity of the cermet plate provides a large active surface for the electrode of the storage battery and good access for the electrolyte. This significantly improves the ion-exchange processes. Moreover, the lamelless plates do not swell up and break up in the process of use, including with blows and vibrations with an acceleration to 100 g.

The greater active surface gives the lamelless storage battery a comparatively lower internal resistance, and at the same time the possibility of use in starter conditions. The lamelless storage batteries operate well under low temperature conditions.

In terms of their specific characteristics, the KNG storage batteries are somewhat inferior to the silver-cadmium storage batteries at positive temperatures, but surpass them in discharging under low temperature conditions.

In terms of service life and shelf life, the lamelless cadmium-nickel storage batteries are significantly superior to the silver-zinc, silver-cadmium and lead ones, but are inferior to the KN and ZhN lamel batteries. Among the drawbacks of the KNG storage batteries are the increased nickel consumption in manufacturing the plates, and, as a consequence of this, the increased production costs.

In terms of their operating characteristics, convenience and simplicity of maintenance, as well as trouble-free use, the KNG storage batteries in no way differ from the widely used KN and ZhN storage batteries.

According to the advertisements of the Saft firm, the lamelless storage batteries have successfully replaced the lead batteries in motor vehicles.

In contrast to the lamel batteries, the lamelless storage batteries except the KNB-60, are made in plastic vessels with leak-proof caps, and this provides their good safekeeping in use.

Figure 40 shows the design of the lamelless cadmium-nickel storage battery, the KNB-25. The storage battery has a container 4 from shock-proof plastic, a styrene copolymer, with a top 1 from the same material. On the top are the terminals supporting the blocks of positive 3 and negative 2 plates. The air plug in the KNB-25 storage battery has been manufactured from steel. In other types of storage batteries, the air plugs are made from polystyrene. In the KNB-25 storage battery, grids of vinyl plastic have been used as the separator. In other KNB batteries, a separation is used made from polyamid fiber combined with kapron fabric.

The use of plastic containers, tops and plugs in a majority of the types of lamelless storage batteries has significantly raised the resistance to corrosion of the storage battery, and has minimized the parasite leaks and short circuits through the top, as occurred in using the KN and ZhN lamel batteries.

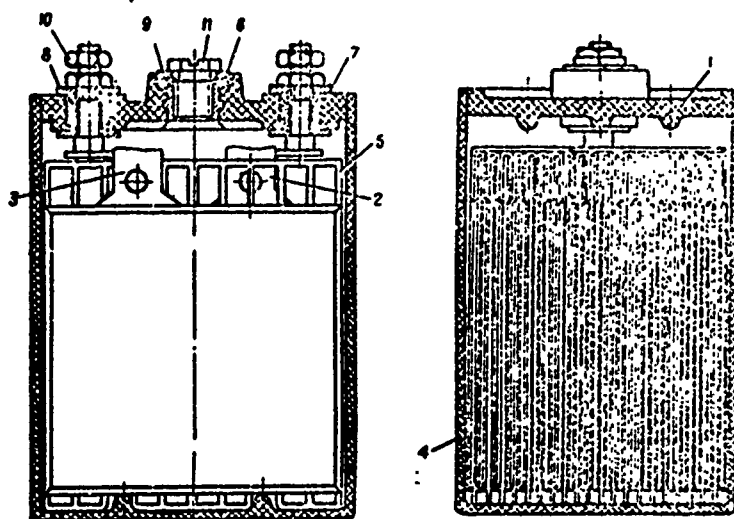


Figure 40. Design of the KNB-25 cadmium-nickel lamelless storage battery;

1 -- top; 2 -- block of negative plates; 3 -- block of positive plates; 4 -- container; 5 -- separator; 6, 7 -- packings; 8 -- packing washer; 9 -- washer; 10 -- nuts; 11 -- cap.

The advantages of the KNB storage batteries, in comparison with the lamel ones, can be seen by comparing the 2FKN-8-11 battery with the 2KNB-20 lamelless storage battery (Table 17).

As follows from the table, the 2KNB-20 battery, which has a volume and weight respectively 45 percent and 10 percent greater than the 2FKN-8-11 battery, produces 150 percent more capacitance than the lamel battery. Here it must be kept in mind that the 2FKN-8-11 battery was discharged over 16 hours, and the 2KNB-20 battery in 4 hours. In discharging the 2FKN-8-11 battery in 4 hours, its characteristics would have been significantly worse.

The range of KNB batteries and storage cells is comparatively slight, however, considering the possibility of series and parallel connecting, it is possible to make up combinations of any voltage and capacitance from the KNB batteries.

Table 17

Comparative Characteristics of the 2FKN-8-11 and
2KNB-20 Storage Batteries

Characteristics	Unit	2FKN-8-11	2KNB-20
Voltage	v	2.52	2.52
Capacitance:	a-hr		
At temperature of +20°		8.0	20.0
At temperature of -20°		6.0	18.0
At temperature of -40°		1.6	6.5
Discharge current	amps	0.5	5.0
Dimensions:	mm		
Length		160	163
Width		32	44
Height		120	125
Volume	dm ³	0.614	0.895
Weight	kg	1.45	1.60
Specific capacity			
	amps		
For volume	<u>dm³</u>	13.0	22.3
	amp-hr		
For weight	<u>kg</u>	5.5	13.5
Specific energy:			
	watt-hr		
For volume	<u>dm³</u>	32.5	55.8
For weight	<u>watt-hr</u> <u>kg</u>	13.75	31.3

Figure 41 shows the 4KNB-20, 8KNB-25, 2KNB-2 and 3KNBN-1.5 batteries.

The basic characteristics of the cadmium-nickel lamelless storage batteries are given in Table 18.

The guaranteed service life of the KNB storage batteries is 250-400 cycles depending upon the type of battery, but in practical terms it is close to the service life of the KN lamel storage batteries.

The shelf life of the lamelless storage batteries in a dry and wet state is the same as for the lamel batteries.

The self-discharge of the KNB storage batteries and cells after 30 days of storage in a charged state lies within limits of 18-20 percent at room temperature. Self-discharge declines at a lower temperature.

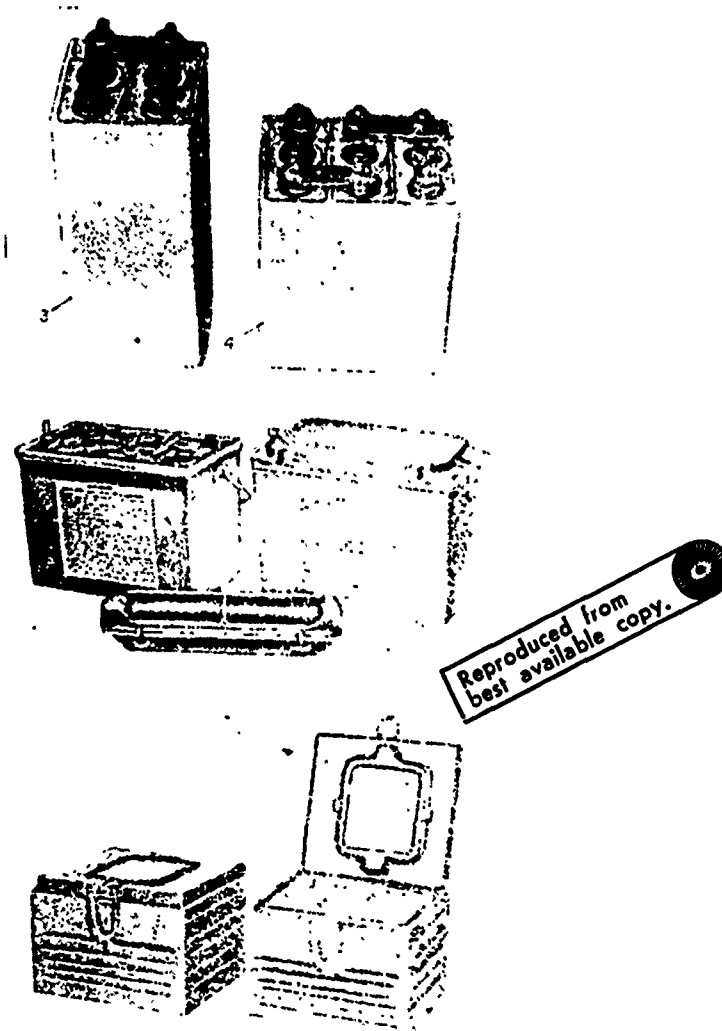


Figure 41. Photograph of lamelless storage batteries:
 1 -- 4KNB-20; 2 -- 8KNB-25; 3 -- 2KNB-2; 4 -- 3KNB-1.5

Figure 42 gives the discharge curves for the lamelless batteries at varying temperatures. These curves show that the KNB storage batteries at a temperature of -40° produce from 30 to 50 percent of their initial capacitance, and this recalculated for the specific energy will be 15-18 $\frac{\text{w-hr}}{\text{kg}}$, that is, the amount of the specific energy of the lamel batteries at kg a temperature of $+20^{\circ}$. In making the curves of Figure 42, the electrolyte temperature was measured.

Table 18

Cadmium-Nickel Lamelless Storage Cells

1) Тип батареи	2) Напряжение, В	3) Емкость, а·ч		4) Ток разряда, а	5) Конечное напряжение при разряде, В	6) Ток заряда, а	7) Время заряда, ч	8) Вес, кг	9) Габариты, мм			10) Удельная плотность, г/см ³	
		11) при +20°	12) при +40°						13) Длина	14) Ширина	15) Высота	по объему, г/см ³	по весу, кг
KNEN													
2КНБН-1,5	2,52	1,5	0,8	0,15	1,8	0,5	6	0,15	35	35	60	46	30
3КНБН-1,5	3,78	1,5	0,8	0,15	2,7	0,5	6	0,22	55	35	60	46	24
KNE													
2КНБ-2	2,52	2,0	1,2	0,4	1,8	0,4	8	0,22	36	36	92	42	23
4КНБ-15	5,2	15	5,5	5,0	4,0	5,0	5	2,1	112	83	125	65	36
2КНБ-20	2,52	20	6,5	5,0	2,0	7,0	5	1,6	163	44	125	56	31
4КНБ-20	5,2	20	7,0	6,5	4,0	7,0	5	3,2	180	93	127	47	31
4КНБ-25	5,2	25	12	5,0	4,0	8,0	5	5,8	180	151	132	37	22
8КНБ-25	10,4	25	16	7,5	8,0	8,0	5	7,5	190	180	132	55	33
10КНБ-60	12,6	60	30	15	10	20	4,5	30	450	178	225	42	25

Key:

1. Type of battery
2. Voltage, volts
3. Capacitance, amp-hrs
4. Discharge current, amp
5. End discharge voltage, volts

6. Charge current, amp
7. Charge time, hours
8. Weight, kg
9. Dimensions, mm
10. Specific energy
11. at +20°

12. at +40°
13. Length
14. Width
15. Height
16. volume, whr/dm³
17. weight, whr/kg

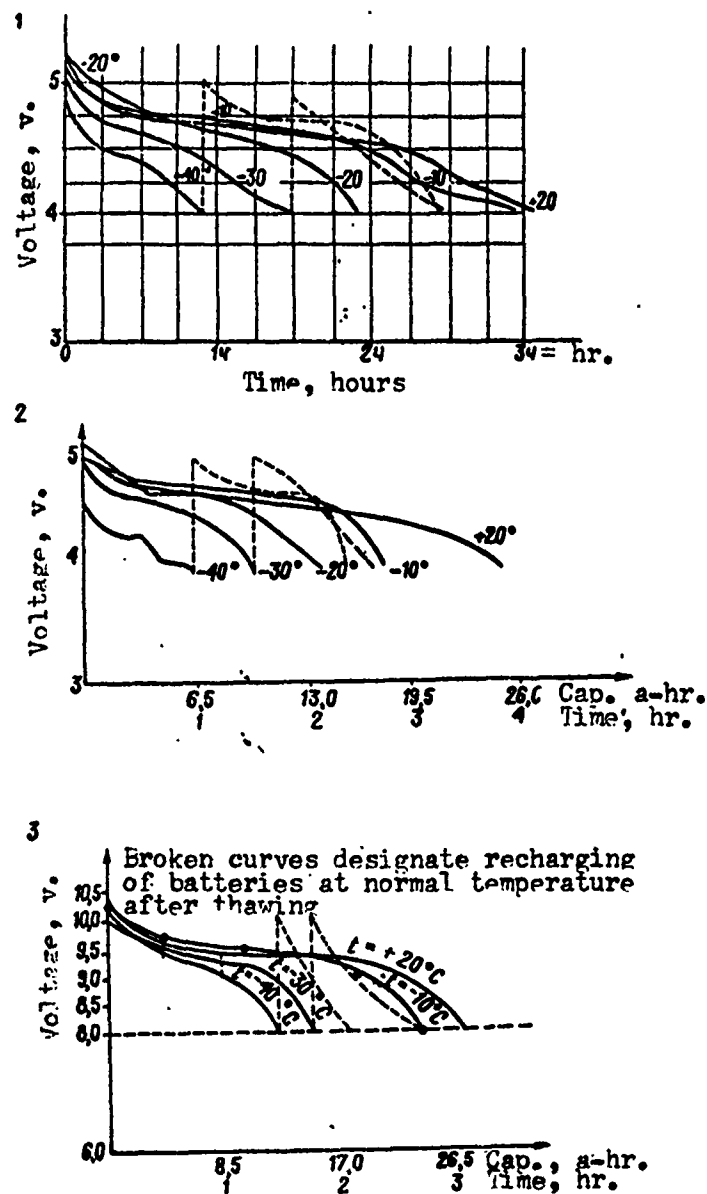
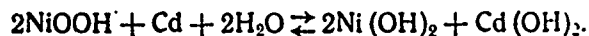


Figure 42. Discharge characteristics of the lamelless KN storage batteries;

- 1 -- 4KNB-15 battery, discharge to fixed resistance of 1 ohm;
- 2 -- 4KNB-20 battery, discharge with a 6.5-amp current;
- 3 -- 8KNB-25 battery, discharge with 8.5-amp current.

The chemical processes in charging and discharging occur according to the cycle:



The high specific characteristics of the lamelless storage batteries and their good output of capacitance under low temperature conditions provide a basis for their extensive use in various portable equipment.

In terms of operating method, the KNB storage batteries virtually do not differ from the lamel KN and ZhN storage batteries. The electrolyte for the KNB storage batteries can be both potassium as well as a composite one with an admixture of lithium hydroxide. In the summertime, the KNB storage batteries are filled with a composite electrolyte, with a density of 1.19-1.21, and at a temperature of -20° and lower with an electrolyte of KOH with a density of 1.27-1.29, but without the admixture of lithium hydroxide. A sodium electrolyte is not used in the lamelless storage batteries.

The water used in preparing the electrolyte should not contain impurities, particularly iron and silicon salts, the presence of which reduces the service life of the battery.

Before charging it is essential to remove a portion of the electrolyte from each battery using a rubber bulb or syringe. This operation should also be carried out in the process of charging when the level of the electrolyte rises.

After charging, the batteries are given time for settling with the top open, and during this time the gases from the electrolyte are given off. The process of eliminating the gases continues from 8 to 24 hours depending upon the type of battery and the method of using it. If the battery has an air plug, then it is possible to restrict oneself to an 8-hour stand. If the battery is connected with dummy plugs and is discharged under vibrating conditions during transporting or with the plugs facing downward, in this instance, there must be a 24-hour stand for removing the gases, since otherwise the battery containers will be ruptured.

When necessary the KNB batteries can be connected after 4 or 4.5 hours of standing, but then at the first opportunity, the plugs should be removed and the accumulated gas allowed to escape. This operation should be carried out during the discharging of the battery several times every 2-3 hours. After standing, the KNB batteries should be topped off with the previously removed electrolyte up to the level of the upper edge of the plates or 5-10 mm above the edge.

The further improvement of the cadmium-nickel batteries has led to the development of storage batteries capable of providing capacitance at a temperature of -50° . This problem has been solved in the tablet battery, the active materials of which, in the form of a set of tablets, form electrode columns. The specific energy of a tablet KN storage battery is

60-70 percent greater than the specific energy of the lamel batteries and 20-25 percent greater than the energy of the lamelless batteries of the KNB-60 type. Here the service life of the tablet batteries is 100-150 percent higher than the lamelless, while the cost is half the amount.

The tablet batteries are also being developed on an iron-nickel base for replacing the 6ST-42 and 6ST-68 lead starter batteries. The new batteries in terms of specific energy correspond to the lead starter batteries, however their service life is at least 5 years.

Another method for increasing the specific characteristics of the KN batteries has been realized in the KN storage battery with pressed electrodes. This makes it possible to raise the specific characteristics by 100 percent in comparison with the KN-10 lamel batteries. The new 2KNP-20 pressed electrode storage batteries, in terms of operating under low temperature conditions, are significantly superior to the lamel batteries, although somewhat inferior to them in terms of service life.

The new batteries of the tablet type and those with pressed plates, in terms of specific characteristics, are inferior to the silver-zinc storage batteries by all of 100 percent, however their operability at low temperatures is significantly higher than the silver-zinc storage batteries.

The Nickel-Zinc (NTs) Alkaline Battery

The first attempts to develop a nickel-zinc storage battery go back to 1867, when a storage battery was proposed with a negative electrode made from metallic zinc and a positive one from nickel oxide Ni_2O_3 . The use of metallic zinc as the negative electrode promised great prospects for developing a storage battery with high specific characteristics, since the electromotive force of the zinc-nickel electrochemical couple equals 1.83 volts, while the emf of the nickel-cadmium couple equals 1.4 volts, and the silver-zinc couple 1.56 volts.

As was the case with the silver-zinc storage battery, where the basic difficulties involved the development of an insoluble negative electrode, here as well over a long period of time searches were conducted for a zinc electrode, until in the 1930s an electrode from powdered zinc was proposed for this system. Subsequently this electrode was used for the silver-zinc storage battery.

With the appearance of cermet electrodes from nickel oxide, V. N. Flerov and his associates were able to develop a NTs storage battery suitable for industrial manufacture. In design terms, the NTs storage battery virtually does not differ from the silver-zinc one (Figure 43). Here, like the STs storage battery, the electrolyte does not participate in the electrochemical reaction.

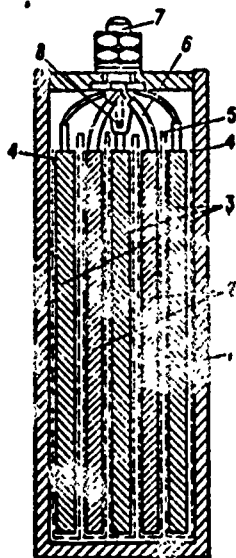


Figure 43. A nickel-zinc storage battery;

1 -- polystyrene container; 2 -- negative electrode; 3 -- positive electrode; 4 -- capron cover; 5 -- cellophane casing; 6 -- insulating tube of negative lead; 7 -- terminals; 8 -- plug.

or



This process is not completely reversible, as a consequence of the unequal current efficiency of the positive and negative electrode. The positive nickel oxide electrode produces around 90 percent,

and the zinc electrode 100 percent, and for this reason in charging there is a constant possibility of overcharging the negative zinc electrode. This leads to the oxidation of the separator film, and causes an accelerated process of dendrite formation and the wearing out of the battery.

The voltage of a NTs storage battery at room temperature is 1.6-1.7 volts, that is, greater than for the STs storage battery.

Among the particular operating features of the NTs storage batteries, we must mention the necessity of careful supervision of the voltage during the charging process, since the charge curve does not have any voltage jumps by which it would be possible to judge the end of charging. Moreover, in considering the uneven capacitance efficiency of the electrodes, it is essential to make as deep a discharge of the NTs storage battery as possible for the purpose of eliminating the reserve capacitance in the negative electrode.

In terms of the design of the plates, the NTs storage battery is classified as a lamelless storage battery. Its positive electrode is manufactured by pressing with subsequent firing and saturating, while the negative one consists of a pressed mass of zinc powder in a mixture of zinc oxide and starch, like the STs storage battery. The separation of the positive plates has been made from capron fabric, and that of the negative plates from triacetate film.

In contrast to the STs storage batteries, in the NTs storage battery, a composite electrode is used consisting of KOH with the addition of lithium monohydrate in a quantity of five grams per liter of solution. The electrolyte density is 1.12-1.18.

The chemical reaction occurring in the process of the battery's operation are:

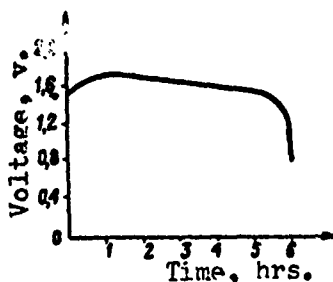


Figure 44. Discharge curve of a NTs-15 nickel-zinc battery at a temperature of +20° centigrade with a 3-amp current.

The industrial model of the NTs-15 nickel-zinc battery has a nominal capacitance of 15 amps per hour (Figure 44), and with discharging under 3-hour conditions at a temperature of -30°, it produces around 30 percent of its rated capacitance (in voltage one volt), and with less complete discharging up to 1.3 volts or 20 percent of the rated capacitance.

The NTs battery is charged with a 5-amp current for six hours (normal charge) to a voltage of not more than 2.1 volts. When necessary it is possible to have quick charging with a 15-amp current for one hour.

Self-discharge after 30 days of storage in a charged condition is the same as for the lamel batteries, 18-25 percent.

In terms of its specific energy (57 watts per hour per kg), the nickel-zinc storage battery surpasses the best types of lamelless KNB storage batteries, although it is not as good as the silver-zinc ones.

Industry also produces the 2RNTs-10 nickel-zinc storage battery with a voltage of 3.4 volts. With discharging to 3.0 volts, the battery allows 15 charge-discharge cycles with a capacitance of from 15 to 10 amps per hour (by the end of the service life). A current of 1 amp is considered the normal discharge current. With systematic discharges with a 1-amp current to a voltage of 3.3 volts, the service life of the battery increases to 250-300 cycles.

The self-discharge of the 2RNTs-10 battery is 80-90 percent over 30 days of storage. The shelf life of the batteries filled with the electrolyte is 6 months. At a temperature of -20° centigrade, the capacitance of the battery is 8-10 percent of the nominal capacitance (with a discharge to 3.0 volts).

An indisputable merit of the NTs battery is its cheapness. It is half the cost of the KNB storage batteries which are equal to it in capacitance and 300 percent cheaper than the silver-zinc batteries.

The NTs batteries are most suited for powering units with brief operating conditions such as: lighting instruments, powerful filament circuits of radio sets and field geological and geophysical equipment.

Silver-Zinc (STs) Storage Batteries

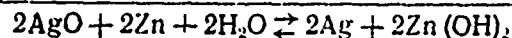
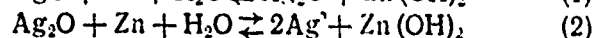
The suitability of the silver-zinc electrochemical couple for use as a current source was established by Volta. However, as a storage battery, this couple was patented only in 1898, and the practical use of the silver-zinc storage battery began in 1943 after the development of the insoluble zinc electrode. Another obstacle to the development of the STs storage battery was the absence of the necessary separation material which possessed both good permeability with ion exchange as well as good mechanical properties, density and elasticity which would prevent the growth of silver dendrites.

The positive electrode of a STs battery is manufactured by pressing powdered metallic silver on a wire carcass, the current lead. After pressing, the plate is fired in a furnace at a temperature of around 400°. This gives it the required strength and porosity.

The negative electrode is a mass which is also pressed on a wire filament lead consisting of zinc oxide (70-75 percent) and zinc powder (25-30 percent). The negative electrode manufactured in this manner is not soluble in the alkaline electrolyte, since with its oxidation the plate pores are filled with zinc hydroxide and oxide which are insoluble in the small quantity of electrolyte.

The most suitable separation for the STs storage battery has turned out to be film from hydrated cellulose (cellophane), which, in swelling in the electrolyte, packs the assembly and prevents the shifting around of the zinc electrodes. The high density of the electrode assembly of the STs battery provides for its high mechanical properties.

The chemical processes occurring in a STs storage battery are described by the equations:



The given total reaction relates to the starter discharge conditions when the zinc is not able to be dissolved in the alkaline electrolyte and form the potassium salt of zincic acid, potassium zincate K_2ZnO_2 .

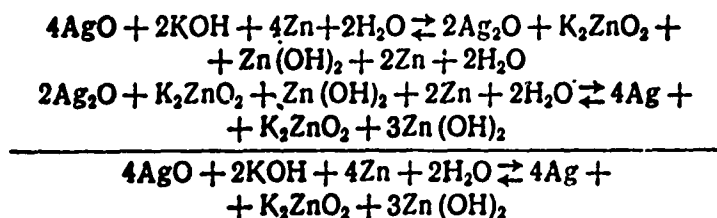
The equations (1) and (2) illustrate the characteristic discharge curve of the STs storage battery (Figure 46), where the process of discharge is broken up into two periods: the first from a voltage of 1.8 volts to 1.5 volts, and the second on a level of 1.5 volts to the end of the discharge.

Equation (1) corresponds to a discharge period of from 1.8 volts to 1.5 volts, where the chemical process consists in the oxidation of the

zinc electrode and the formation of the hydrate of zinc oxide. At the same time, the positive electrode of silver oxide Ag_2O is reduced to Ag_2O .

The second equation relates to discharging on a level of 1.5 volts, when the zinc residue on the negative electrode is converted to a hydrate of zinc oxide, while the silver oxide Ag_2O is reduced to metallic silver.

Under long discharge conditions, the chemical processes in the STs battery are complicated by the formation of potassium zincate K_2ZnO_2 , when the reaction occurs according to the equations:



The first of the equations given above shows the process of the dilution of the zinc in the alkaline electrolyte with the formation of potassium zincate K_2ZnO_2 , the oxidation of the zinc into a hydrate of zinc oxide Zn(OH)_2 and the reduction of AgO into Ag_2O . The second equation describes the further process of zinc oxidation and the reduction of silver oxide into metallic silver. The first equation relates to a degree of discharge of from 1.88 to 1.5 volts and the second to a discharge at 1.5 volts.

The formulas given above characterize well the chemical processes in the STs storage batteries, the discharge of which is accompanied by a loss of water and charging by its formation.

The design of the STs storage battery is shown in Figure 45. The silver-zinc batteries are made in transparent and semiluculent vessels from chemical and heat-proof plastic making it possible to have visual control over the electrolyte level.

The lid of the vessel is made from the same material as the vessel itself. To it are attached the terminal poles with the bunches of silver leads soldered to them from the positive and negative plates of the battery. The top has an opening for adding electrolyte and for the escape of gases. Ordinarily the opening is covered with a breathing plug which provides for the use of the battery in any position, but in certain types of the battery, the filling hole is covered by a plastic cap.

The zinc electrodes in the STs storage battery are placed in the separation in pairs. In placing them in the vessel, a silver positive electrode is placed in each pair between the individual plates. The positive electrodes

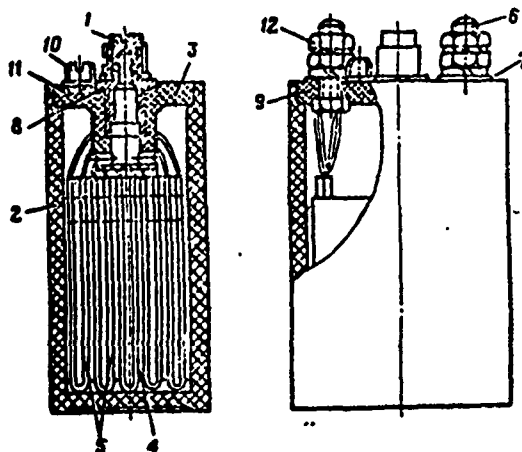


Figure 45. The design of a silver-zinc storage battery:
 1 -- valve; 2 -- tank; 3 -- top; 4 -- positive electrode;
 5 -- set of negative electrodes; 6 -- terminal; 7 -- washer;
 8 -- packing gasket; 9 -- gasket; 10 -- plug; 11 -- packing
 gasket; 12 -- nut.

are also placed between the clusters of negative plates.

The plates are assembled in such a manner as to consider their swelling in the process of use, since the compactness of assembly determines the resistance of the STs battery to mechanical stresses related to transporting. Moreover, the compactness of assembly also determines such an important characteristic of the battery as the service life, since with compact assembly, the negative electrode is deprived of any possibility of becoming misshaped as a consequence of the shifting around of the zinc.

On the container of the assembled battery, two horizontal marks are made in red paint indicating the tolerable electrolyte level in the storage battery in charging (upper mark) and discharging (lower mark). In certain types of batteries the containers of which have been manufactured from insufficiently transparent plastic, the electrolyte level must be observed from the side of the plate ribs, in tipping the vessel.

The silver-zinc batteries are used as individual cells as well as assembled into batteries. At present, our industry produces a large quantity of various types of silver-zinc storage cells and batteries with a capacitance of from 0.5 to 120 amps per hour. The basic characteristics of them are given in Table 19.

Table 19

Silver-Zinc Storage Cells and Batteries

Имя аккумулятора 1) (dataset)	Среднее напряжение, В	3) Размеры			4) Заряд		5) Удельные, м.м			6) Вес с зажимом, кг	7) Удельная энергия		
		длина, мм	ширина, мм	высота, мм	ток, А	время, ч	длина, мм	ширина, мм	высота, мм		по объему, м.м³	по массе, г/см³	по объему, м.м³
STsSO.5	1.5	0.5	10	1.0	0.025	25	24	12	37	0.024	58	31	
STsSl.5	1.5	1.7	10	1.0	0.15	13	28	14	50	0.035	112	73	
STsS3	1.5	4.5	10	1.0	0.5	10	44	19	61	0.105	123	63	
STsK3	1.5	4.0	1	1.0	0.5	8				0.105	112	57	
STsD3	1.5	6.0	20	1.0	0.4	17				0.110	168	82	
STsM3	1.5	3.0	3	1.0	0.3	16				0.105	75	44	
STsS5	1.5	8.0	10	1.0	0.8	11	47	34	69	0.180	109	67	
STsD5	1.5	12	20	1.0	0.8	17				0.200	163	90	
STsM5	1.5	5.5	3	1.0	0.45	15				0.185	75	44	
STsE5	—	2.0	—	—	—	—				0.200	—	—	
STsSl2	1.5	11	10	1.0	1.0	12	50	23	101	0.225	138	73	
STsD12	1.5	13	20	1.0	0.8	19				0.230	163	85	
STsM12	1.5	7.0	3	1.0	0.6	15				0.190	88	55	
STsSl5	1.5	15	10	1.0	1.5	11	50	29	101	0.275	145	82	
STsD15	1.5	18	20	1.0	1.3	16				0.280	177	100	
STsM15	1.5	10.5	3	1.0	0.8	16				0.280	101	56	

Key:

1. Type of storage cell (battery)

2. Average voltage, v.

3. Discharge

4. Charge

5. Dimensions, mm

6. Weight with electrolyte, kg

7. Specific energy

8. Capacitance, amp-hr

9. Duration, hours

10. End voltage, v.

11. Current, amp.

12. Time, hours

13. Length

14. Width

15. Height (without terminal)

16. for volume, whr/dm³

17. for weight, whr/kg

Table 19 (Cont.)

1) Тип акустического (детектора)	2) Среднее значение показаний	3) Разряд			4) Заряд		5) Габариты, мм			6) Вес с транзистором, кг	7) Удельная энергия	
		Скорость срабатывания	Амплитуда ночного света	Количество элементов	Ток, мА	Средняя длина	Ширина	Высота (без батарей)	по объему, мг/см ³		по площади, мг/см ²	
СТсК18	1.5	14	1	1.0	3.0	7	50	35	104	0.345	115	61
СТсС18	1.5	19	10	1.0	2.0	10				0.335	155	91
СТсК18	1.5	12	3	1.0	0.8	18				0.330	99	55
СТсД18	1.5	25	20	1.0	1.5	20				0.360	210	104
СТс25	1.5	25	3	1.0	1.5	18	48	48	125	0.330	130	114
СТсК25	1.5	20	1	1.0	5.0	6	50	50	118	0.555	102	54
СТсС25	1.5	30	10	1.0	3.0	11				0.545	152	82
СТсД25	1.5	40	20	1.0	2.5	18				0.540	200	110
СТсМ25	1.5	23	3	1.0	2.0	16				0.510	117	68
СТсЕ25	—	6	—	—	—	—				0.530	—	—
СТсК40	1.5	50	1	1.0	7.0	8	56	52	141	0.785	180	95
СТсС40	1.5	42	10	1.0	5.0	9				0.785	153	80
СТсД40	1.5	70	20	1.0	4.5	17				0.825	260	128
СТсБ40	—	10	—	—	—	—				0.780	—	—
СТсК50	1.5	54	1	1.0	8.0	8	66	51	144	0.985	167	82
СТсС50	1.5	50	10	1.0	6.0	9				0.985	155	76

Key: [See page 103.]

Table 19 (cont.)

1) Тип аккумулятора (батарея)	2) Среднее напряжение	3) Размеры			4) Заряд			5) Габариты, мм			6) Вес с транском, кг	7) Удельная энергия	
		а) высота, мм	б) длина, мм	в) толщина, мм	г) напряжение, В	д) ток, А	е) время, ч	ж) длина, мм	з) высота, мм	и) ширина, мм		по объему, мг/см ³	по весу, Вт/кг
STsD50	1.5	83	20	1.0	1.0	5.5	17				0.990	260	126
STsM50	1.5	40	3	1.0	1.0	3.0	17				0.850	124	71
STsE50	—	15	—	—	—	—	—				0.950	—	—
STsS70	1.5	80	10	1.0	1.0	8.0	11	94	149	52	1.450	165	83
STsD70	1.5	130	20	1.0	1.0	8.0	19				1.505	268	130
STsM70	1.5	55	3	1.0	1.0	4.5	15				1.300	113	63
STsB70	—	25	—	—	—	—	—				1.450	—	—
STsS100	1.5	110	10	1.0	1.0	10.0	11	108	168	51	1.750	177	94
STsS120	1.5	130	10	1.0	1.0	12.0	12	71	212	55	1.985	235	98
STsS1.5	4.5	1.5	5	3.0	3.0	0.2	9	44	54	30	0.150	95	45
3STs5	4.5	7.5	3	3.0	3.0	0.5	20	96	77	45	0.590	100	57
5STs5	7.5	7.5	3	5.0	5.0	0.5	20	160	77	45	1.020	102	55
3STs25	4.5	25	3	3.0	3.0	1.5	18	141	136	48	1.050	120	110
8STs45	12	50	3	8.0	8.0	4.5	15	200	160	110	6.480	165	93
15STs45	22.5	45	10	15.0	15.0	4.5	15	432	170	126	16.0	110	63

Key: [See page 103.]

The service life of the STs batteries, depending upon purpose and discharge conditions, varies from 10 to 100 charge-discharge cycles. The STsK storage batteries designed for use under brief discharge conditions have a service life of 10 cycles and a shelf life in a filled state of 4 months; the STsS which are designed for average discharge conditions have a service life of 25 cycles and a shelf life of 6 months; the STsD for long discharge conditions have a service life of 30 cycles and a shelf life of 6 months; the STsM are for average conditions but with a long service life and have 100 cycles with a shelf life of 9 months (the letter M in the designation of these batteries means "multicycle"); the STsB which are for use in buffer conditions do not have an established service life.

The STs25 battery in terms of service life and shelf life (60 cycles and 9 months respectively) can be considered in the multicycle batteries.

The shelf life of the dry STs batteries which have not been used and which have not been filled with electrolyte is guaranteed from 3 to 8 years.

The reason for the comparatively short service life and shelf life of the STs batteries is the destruction of the separation in the alkaline electrolyte and the growth of silver and zinc dendrites (acicular crystals) in the process of the battery's use. Ultimately these lead to a point short circuit between the electrodes and the failing of the battery.

One of the reasons for the accelerated growth of dendrites is the overcharging of the battery when there is strong oxidation of the triacetate separator film and its destruction. Film oxidation also occurs with the protracted storage of the STs batteries with open vents.

Self-discharge for all types of STs batteries, with the exception of the STs1.5, is 10 percent for 30 days of storage in a charged state. With an increase in temperature, self-discharge increases and at a temperature of $+40^{\circ}$ and above, the STs batteries lose a portion of their capacitance permanently.

The silver-zinc batteries, in terms of their specific characteristics, are significantly superior to all of the known diverse sources of current. The small weight, insignificant size in relation to a unit of capacitance, the increased voltage, the independence of capacitance from the discharge current, and the usability with a reduced atmospheric pressure make the STs batteries irreplaceable for use in small-sized portable equipment.

The discharge characteristics of the STs batteries are given in Figure 46.

Under low temperature conditions, the STs storage batteries produce an increased capacitance in comparison with the KN lamel batteries. From the discharge curves (Figure 47), it follows that the STs battery, at a temperature of -30° , is capable of producing 40-50 percent of the rated capacitance, and at a temperature of -40° , around 20 percent (with a

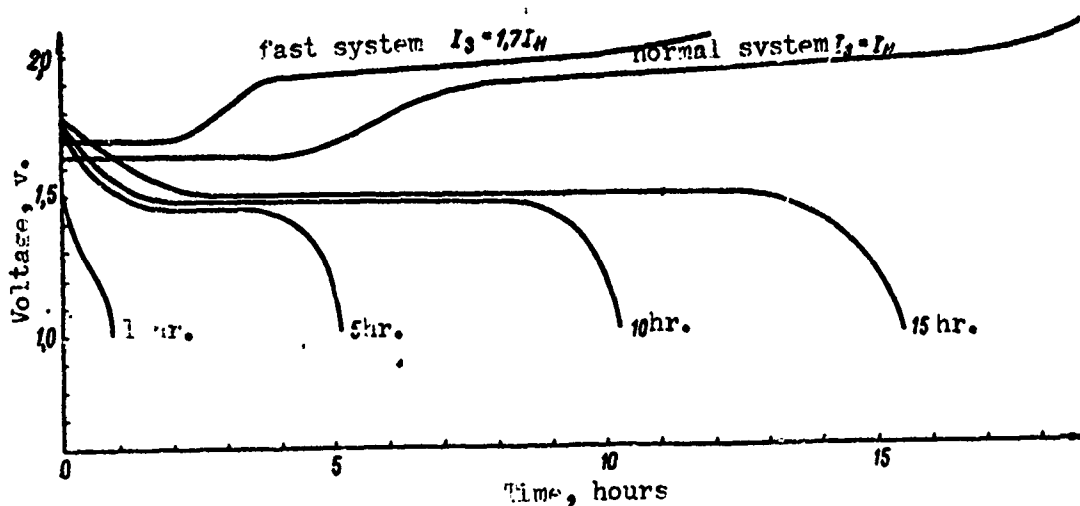


Figure 46. Standard charge and discharge characteristics of the silver-zinc batteries.

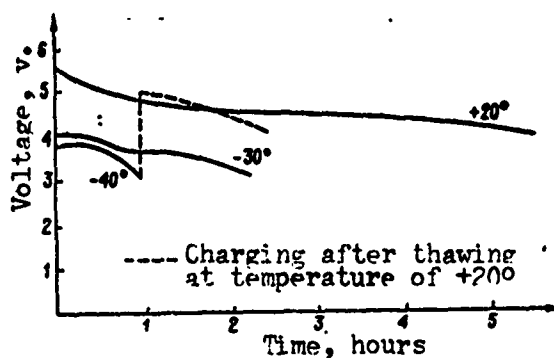


Figure 47. Discharge curves of the 3STs-25 battery with a 5-amp current and varying temperatures.

discharge to an end voltage of 1 volt for the battery).

With a reduced temperature, the internal resistance of the STs battery increases, and as a consequence of this, the STs batteries, at a temperature of -30° and lower are not capable of competing with the lamel-less KN batteries of the KNB type. Complete inoperability of the STs batteries occurs at a temperature of -59° .

With an increased temperature, the internal resistance of the STs battery declines as a consequence of the negative temperature coefficient of its electrolyte.

Among the particular operating features of the STs batteries, we must mention their extreme sensitivity to overcharging and to the purity of the electrolyte. The overcharging of the batteries, as was stated above, leads to the destruction of the separation and to increased dendrite formation. Moreover, in charging several STs batteries in a series connection, it is possible to have a pole reversal of individual overcharged batteries. For this reason, in charging the STs batteries, it is essential to carefully watch the voltage of each battery. By the end of the charging, special attention should be paid to those batteries, the voltage of which has increased in comparison with the remaining batteries. The batteries which have been charged to 2.10 volts should be taken out of the charge circuit to avoid pole reversal.

The complete discharging of the individual cells in a battery should also be prevented, since a battery which has a reduced voltage begins to be charged from the other cells and this can lead to its failure.

Particularly dangerous for the STs batteries is their use in a parallel connection. The capacitance and voltage dissimilarity of the individual cells which is tolerable in a series voltage here is lethal. For this reason, the STs batteries must not be charged and discharged in a parallel connection.

As the electrolyte of the STs cells, chemically pure potassium hydroxide is used with a density of 1.40 and of the ChDA or DhChDA grade. The use of any other electrolyte is impossible, including the customary or composite electrolyte for the KN batteries.

With the loss of electrolyte, it is essential to add it to the appropriate level marked on the container of the STs battery, considering the state of the battery, that is, whether or not it is charged or discharged. It is possible to add only the electrolyte used for the STs batteries supplied with the set for the batteries or an electrolyte made from chemically pure alkali. With the absence of electrolyte, it is possible to top off the battery with distilled water. The topping off with nondistilled water is prohibited.

The requirements for the purity of the electrolyte for the STs batteries are explained by the fact that all the components comprising the active masses of the plates have a high degree of chemical purity. Contamination of the battery with other substances can cause oxidation and destruction of the separation.

The insufficient operability of the STs batteries under low temperature conditions has caused the search for such operating conditions whereby the STs batteries can produce an increased capacitance. Among such conditions are the placing of the STs cell or battery in a warmed casing or the preliminary short circuiting discharge for the purpose of warming the cell, or the heating of the battery with a heating element.

Placing the STs batteries in insulation in and of itself does not provide for their operability at low temperatures, since under conditions of protracted discharge a battery which has been heavily frozen at a temperature of -40° and below is not capable of producing a voltage of more than one volt. For this case, the operability of the battery will be determined by the time it has been kept at the given low temperature, that is, by the temperature of the battery's electrolyte. An insulated battery after 7 or 8 hours of remaining at a temperature of -40° can have a temperature of around -20° in the electrolyte. This will make it possible to drain around 70 percent of its rated capacitance. However, in keeping the battery at the same temperature for more than 30 hours, the temperature in the electrolyte reaches the temperature of the surrounding medium and the battery is virtually useless.

With short discharge conditions (not more than 5 hours), an insulated STs battery is capable of producing greater capacitance even at a temperature of -40° in the electrolyte. Here, the initial voltage of the battery which has been frozen at a temperature of -40° lies within limits of around one volt. Later on, after 5-10 minutes of discharging, there is an increase in voltage reaching 1.2-1.4 volts, and the voltage remains on this level until the end of the discharge. The efficiency of a STs battery in plastic foam insulating 3 mm thick is around 20 percent for these conditions.

The preliminary warming of the STs batteries by their brief short circuit discharging is the most effective, since this method provides for the work of the STs batteries regardless of the time they have been left in the frost and the discharge conditions.

Short circuit self-heating makes it possible to operate the STs battery with a discharge voltage of 1.5 volts. This is particularly valuable for equipment requiring a constant voltage. The losses in the short circuit lie within limits of 20-30 percent. This provides an opportunity for draining around 70 percent of the nominal capacitance of the battery. Naturally, a battery operating under self-heating conditions should have insulating the purpose of which is not to slow down the cooling process of the battery, but rather to preserve the produced heat. This is significantly simpler in design terms.

Any insulators usable in terms of operating conditions can be employed as insulating.

In certain types of equipment, with the aim of slowing down the cooling process of the sources of current, containers have been used the walls of which are made of water-filled vessels. This, considering the great heat capacity of the water, provides a constant temperature for the power source located in such a container over a long period of time.

The use of special heating elements of the STs cells can occur in devices not designed to be carried by a person, since in this instance the heating losses are more than one-half the capacity of the battery and

at a temperature of -40° and lower cannot produce the required effect under the condition of powering them from the same STs battery.

Use under short circuit conditions can lead to a reduction in the service life of a STs battery, however, considering the possibility of improving its characteristics by charging with an asymmetrical current (Chapter V), this reduction is not a crucial one.

Silver-Cadmium (SK) Batteries

Regardless of the fact that the production of silver-zinc batteries has been underway for more than 10 years in the USSR and abroad, up to now it has not been possible to substantially increase the service life and the shelf life of these sources of current which possess the highest specific characteristics.

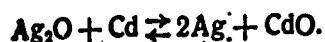
Since a rise in the operational characteristics of the STs batteries is limited by the negative zinc electrode, naturally steps were taken to examine the possibility of using other metals, in particular, cadmium. Cadmium is significantly superior to zinc in terms of its operational characteristics, that is, in terms of the service life under the conditions of a protracted keeping in a strong alkali, and in terms of mechanical qualities, however, being inferior in terms of the amount of electrode potential.

Calculations indicate that a storage battery based on the silver-cadmium electrochemical system is superior, in terms of specific energy, to such electrochemical systems as cadmium-nickel and even zinc-mercury oxide (for the hourly discharge conditions), being inferior to the silver-zinc system.

Since the SK battery is a logical extension of the work done to improve the STs battery, its basic design features maintain the elements of the STs batteries. As the positive electrode of the SK battery, they have used univalent silver oxide pressed on to a wire current lead. The negative electrode is manufactured from cadmium oxide. The material for separation is the same as in the STs batteries, a triacetate film combined with a fibrous material. The assembly of the battery from the electrode packs and their placement in the vessel is as compact as in the STs batteries.

Since the solubility of cadmium oxide in the alkali is very slight, the formation of dendrites and the plate short circuits which accompany them is virtually excluded. However, the low strength of the cellophane separator which breaks down in the process of the battery's use does not make it possible to obtain from the SK batteries a service life close to the KN batteries.

In the SK battery, the electrolyte is a solution of KOH with a density of 1.40. The electrochemical reaction occurs according to the equation:



The sealed SKG batteries, in design terms, are reminiscent of the sealed KN batteries. In the SKG batteries, the negative electrode in terms of mass exceeds the positive one, as a consequence of which, in the charge process, the negative electrode always remains undercharged and does not achieve the potential for the output of free hydrogen.

The charge and discharge curves of the SK battery (Figure 48) are reminiscent of the performance of the STs batteries. The mean voltage of the SK battery lies within limits of 1.05-1.1 volts. The discharge characteristics show an almost horizontal line which is a positive quality of the battery.

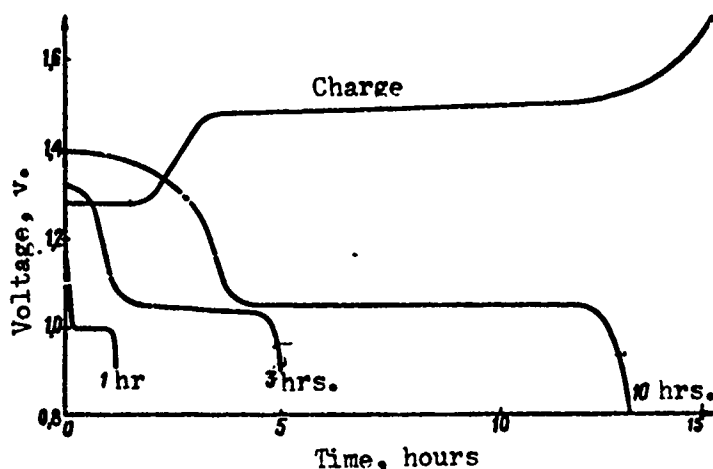


Figure 48. Charge and discharge characteristics of the SK storage battery at a temperature of +20° centigrade.

The SK batteries work well in starter discharge systems. Here, depending upon the discharge conditions, the initial section of the discharge characteristics increases or declines within limits of from 1.4 to 1.0 volts in terms of voltage.

The voltage of the horizontal area on the discharge characteristics depends upon the discharge current. With a short circuit, the voltage in this area is 0.9 volts per cell, with a 1-hour system the voltage equals 1.0 volts, and for a 4-hour system, this value reaches 1.05 volts. This must be considered in designing equipment powered by SK batteries.

The self-discharge of the SK batteries over 90 days of storage in a charged state does not exceed 5 percent. This is a positive quality of

theirs. The shelf life of the SK batteries filled with electrolyte is not less than 1.5 years, including six months in a charged state.

According to the advertising of foreign firms, the silver-cadmium batteries depending upon the discharge conditions are capable of output from 1500 to 3000 cycles.

In terms of their specific characteristics, the SK batteries are somewhere midway between the KNB and STs batteries. The specific weight energy of a SK battery reaches 70 watts per hour per kilogram, and for volume, 130 watts per hour per cubic decimeter.

At low temperatures, the performance of the SK batteries worsens analogously to the STs batteries. The voltage of a SK battery which is being discharged under 2-hour conditions at a temperature of -20° does not exceed 0.8 volts, and 0.4 volts at -40° . For this reason, for the purposes of operating the SK batteries at negative temperatures, it is essential either to warm the cells, if the discharge current is not less than 50 percent of the rated capacitance of the cell, or heat the cell with a brief short circuit.

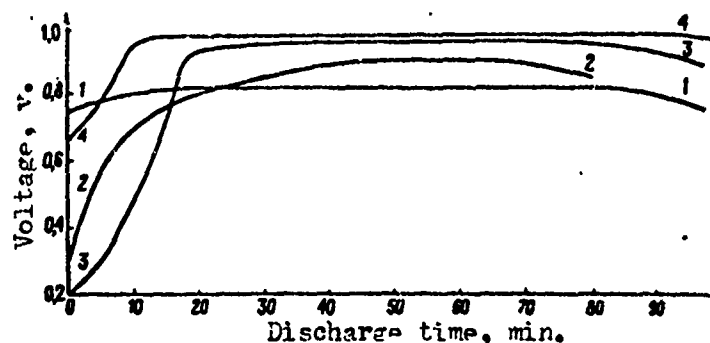


Figure 49. Discharge characteristics of a SK-15 battery at low temperatures:

1 -- 8-amp discharge current, temperature -20° centigrade, without insulating; 2 -- 8-amp discharge current, temperature -35° centigrade, insulating from plastic foam 10 mm thick; 3 -- short circuiting and subsequent discharge with an 8-amp current at a temperature of -40° centigrade; 4 -- short circuiting and subsequent discharge with an 8-amp current at a temperature of -20° centigrade.

Figure 49 shows the discharge characteristics of a SKG battery with a capacitance of 15 amps per hour at low temperatures (2). From this it can be seen how the voltage of the battery increases as it is heated. The battery was surrounded by a layer of plastic foam 10 mm thick. The discharge current was 8 amps. With discharging a battery which had not been

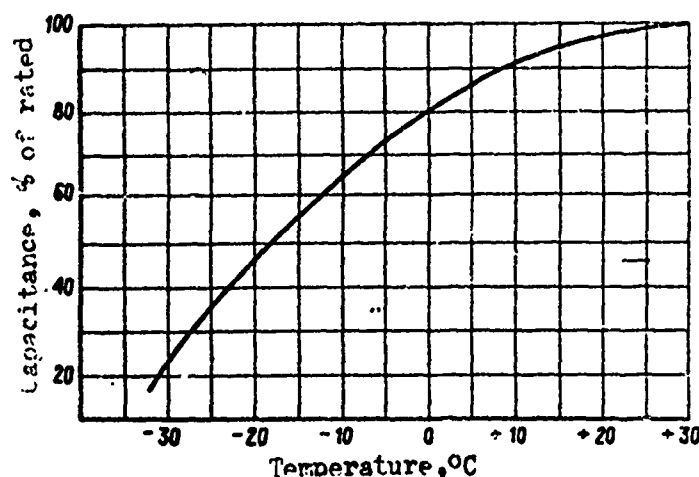


Figure 50. Characteristics of the capacitance dependency of the SK-1.5 batteries upon temperature (without warming) for 3-hour discharge conditions.

Table 20

Silver-Cadmium Storage Batteries

Characteristics	Unit	Cell types				
		SKG1.5	SK15	SK80	SK100	SK300
Voltage	volt	1-1.1	1-1.1	1-1.1	1-1.1	1-1.1
Capacitance	amp-hr.	1.5	15	80	100	300
Discharge duration	hours	3	3	3	3	3
Volt. at end of discharge	volt	0.8-1	0.8-1	0.8-1	0.8-1	0.8-1
Duration of charging ...	hours	10-15	10-15	10-15	10-15	10-15
Dimensions:	mm					
length		28	66	107	107	138
width		14	32	52	52	56
height with terminals		52	100	168	183	255
Weight	kg	0.052	0.4	1.72	1.9	4.65
Specific energy:						
for volume	whr/dm ³	110	105	141	153	181
for weight	whr/kg	41	56	78	84	77

Note. The data on the amount of specific energy have been given from a calculation of the actual capacitance of the SK batteries which exceeds the rated by 30-40 percent.

insulated with plastic foam under the same conditions, no capacitance could be drained from it.

Figure 50 gives the capacitance dependency of the SK batteries upon temperature for 3-hour discharge conditions with noninsulated containers.

The insulating of the batteries with plastic foam makes it possible to drain up to 50 percent of the rated capacitance from the SK battery, in truth, with a lowered voltage (around 0.8 volts).

Another method for providing the operability of the SK batteries is a brief short circuiting for the purpose of sharply raising the temperature of the electrolyte. This method, under the condition of insulating the cells or battery, makes it possible to drain up to 80 percent of the nominal capacitance of the battery at a temperature of -40° , and the discharge curve runs on a level of 1 volt. In the event of using a short circuit for the self-heating of a battery, the service life of the SK batteries, as with the case of the STs batteries, is reduced.

The mechanical qualities of the SK batteries are sufficiently high and are analogous to the qualities of the STs batteries. This is achieved by using shock-proof vessels, compact assembly of the plates and shock absorbing.

The area of use of the SK batteries is just as broad as the silver-zinc ones. This includes: portable equipment, radio sets, geophysical and geological instruments and aviation equipment.

Among the particular operating features of the SK batteries is the necessity of charging them in a three-stage system: the first stage of charging with a current around 30 percent of the rated capacitance, the second of charging with a current of 15 percent of the rated capacitance and the third stage of a protracted charge with a current on the order of 5 percent of the capacitance. Such a charge carried out with a stabilized voltage provides for the charging of the battery without the output of gas.

Table 20 gives the basic characteristics for certain types of SK batteries developed by Soviet industry.

Chapter Three

SEMICONDUCTOR SOURCES OF CURRENT

Just a decade ago, the proportional amount of semiconductor sources of current, in comparison with the chemical ones, was fractions of a percent. At present, the situation has changed sharply. At present, it would be difficult to imagine such areas of technology as space and applied solar energy without semiconductor sources of current.

The processes of generating electrical energy by semiconductor sources of current differ fundamentally from the oxidation-reduction processes of current formation in the chemical sources of energy.

In terms of their electrical properties, solids are divided into metals, semiconductors and dielectrics. Their physical properties are determined by the composition of the nucleus and the state of the electrons surrounding the nucleus, that is, by the strength of the electron bonds in the atoms, by the energy of the electrons and by their mobility.

The electrons surrounding the nucleus form a system of electron shells. In each shell it is possible to find a strictly determined number of electrons. The electrons comprising the external shells of atoms, the so-called valence electrons, are the farthest away from the nucleus, and, consequently, the most weakly linked to it. This circumstance leads to a situation where under certain conditions the atom can lose one or several of these electrons. For example, the thermal movement of the atoms can be the reason for the breaking away of an electron from the atom. Here it may turn out that one or several electrons will be released from the atom at the moment of collision of the particles with one another as a result of a strong blow. The atom which has lost an electron becomes a positive ion, and the electrons which have been released as a result of the collision for a certain period of time will wander freely throughout the entire volume of the solid, until coming into contact with any positive ion or neutral atom.

From what has been stated, it follows that a certain quantity of energy must be expended for the ionization of the atom. However, in such solids as metals, the valence electrons are so weakly bonded with the nucleus that they separate comparatively easily from the atom and wander freely throughout the entire mass of the metal. Here the concentration of free electrons in a cubic centimeter of metal is extremely high, around 10^{22} . And, particularly importantly, this amount is constant and does not depend upon external factors such as temperature, pressure, and so forth.

In metals, both at a temperature of absolute zero (-273°) as well as at the melting temperature, the same number of free electrons is found. This circumstance sharply distinguishes metals from all other solids.

In participating in the thermal movement, the free electrons move in all possible directions at a speed of around 10^8 centimeters per second. Since the free electrons are very numerous and thermal movement is a static process, the number of electrons moving in one direction as an average equals the number of electrons moving in the opposite direction. For this reason, the total charge carried across any section of a metallic conductor with the absence of an external electric field, equals zero.

With the presence of a field applied to the conductor, the electrons gain additional velocity in a direction from the lower potential to the higher, and as a result of this, a flow of electrons arises in the conductor. This is called the electric current.

In moving in a directed manner under the influence of the difference of the potentials, the free electrons on their path experience numerous collisions with the ions of the metal. In other words, any metal possesses a resistance. The resistance of the metal depends upon the temperature. With an increase in temperature, it rises, since the thermal movement of the ions becomes more intense. And, conversely, with a reduction of the temperature, the intensity of thermal movement declines, the number of electron collisions is reduced, and their directed movement is facilitated as the resistance of the metal declines.

The atom of a semiconductor, like the atom of metal, consists of a nucleus and electrons. However, in the semiconductor atom, all electrons, even the farthest away, are rather strongly bonded to the nucleus. This circumstance leads to a situation where with sufficiently low temperatures in the semiconductor there are no free electrons, and consequently, no electric current can flow. Thus, at low temperatures, the semiconductor is an insulator possessing a high electrical resistance.

With an increase in the temperature in the semiconductor, as is the case in metals, the intensity of the thermal vibrations of the atoms and the molecules increases. As a result of the collisions of certain particles, electrons can be released, but there will be few of them, in contrast to a conductor. The free electrons of the semiconductor are virtually identical to the free electrons of the metals. They also can move completely freely within the limits of the body over a certain brief time, the "lifetime," until they combine with some ion.

Thus, in a semiconductor, two processes occur simultaneously: the occurrence of conduction electrons and their disappearance. As a result of this, a dynamic equilibrium is established between the number of free electrons and the number of electrons attached to the ions. Consequently, in a semiconductor there always is a certain quantity of free electrons called the conduction electrons. If a potential difference is created in the semiconductor, then the conduction electrons will begin to move from

the lower potential to the higher one, and current will flow in it.

With an increase in temperature, the number of collisions of atoms increases, and consequently, the number of delta electrons grows, that is, the concentration of conduction electrons rises. Simultaneously with this process, an increase in temperature leads to the more intensive thermal movement of the atoms of the substance. This, in semiconductors, as is the case with metals, leads to an increase in resistance. However, in a semiconductor, the former process prevails over the latter. For this reason, the electric conductivity of semiconductors σ , in contrast to metals, increases with an increase in temperature, but with a reduction in temperature, declines according to the law:

$$\sigma = \sigma_0 e^{-\frac{\Delta E}{2kT}},$$

where ΔE -- the width of the semiconductor's forbidden band characterizing the electrical properties of the material (this will be taken up below);

σ_0 -- coefficient with a numerical value of 10^5 ;

k -- the Boltzmann constant equal to 1.38×10^{-16} ergs per $^\circ$;

T -- absolute temperature.

Thermal movement is not the only reason for the occurrence of conduction electrons in the semiconductor. Since electrical conductivity of a semiconductor arises as a consequence of the fact that previously bonded electrons are released, it is sufficient to give the electrons the necessary energy for their release in order that conductivity occur. In addition to thermal movement, this energy can be supplied to the semiconductor electron by electromagnetic radiation (including light), by high-speed elementary particles, by a strong electric field, and so forth.

Even in the last century it was discovered that the resistance of a number of semiconductors alters sharply depending upon illumination. This phenomenon, called the internal photoelectric effect, can be explained from the standpoint of the just-described phenomena.

Let us examine the energy spectrum of the valence electrons in semiconductors and metals.

Each electron possesses a certain energy. But the electrons comprising an atom can be only in "allowed" energy states, and all the electrons of the atom are distributed according to strictly determined energy states, or, as they are called, levels. Not more than two electrons can be found on each energy level.

Since the electrons are bonded to the nucleus by attracting forces, the transfer of the electron from a lower energy level to a higher one involves the consumption of energy which must be supplied to the electron. With the reverse transfer, the electron loses a certain portion of energy. And due to the fact that the electron in the atom can occupy only strictly determined "allowed" levels, both the loss of energy by the electron as well as its acquisition occur, of necessity, in jumps, and not continuously.

Aside from the allowed, that is, basic levels, in a semiconductor there are other excitation levels which differ from the basic ones in the fact that for a transfer to them the electrons must be supplied with additional energy.

In a solid, atoms are located so close to one another that there is a grouping of them in terms of energy levels. These levels form a zone or energy band. The allowed band is formed in this manner. Aside from the energy bands there are also bands in which the electrons may not be. These areas are called forbidden bands.

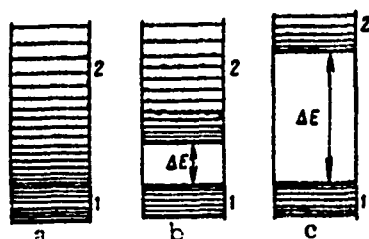


Figure 51. Distribution of energy bands:
a -- in metal; b -- in ion semiconductors; c -- in dielectric
1 -- basic (valent) band; 2 -- conductivity band (excited level band);
 ΔE -- forbidden bands.

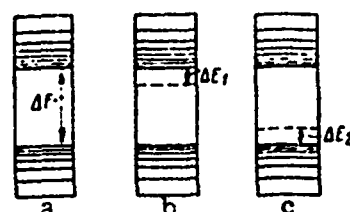


Figure 52. Diagram of energy levels of electrons in a semiconductor:
a -- intrinsic semiconductor;
b -- semiconductor with donor impurities; c -- semiconductor with acceptor impurities.

In a metal (Figure 51a), the band of excited levels is directly adjacent or overlapping the basic band. At a temperature close to absolute zero, the basic band is filled with electrons, while the band of excited levels is free. In order for the electrons to move from the basic band into the band of excited levels, it is essential that they be given additional energy. An electric field can be such energy, and under its action, the electrons will begin to leave the basic band and move to the higher energy level of the excited band. As a result of this, electric conductivity arises in the conductor.

The structure of the energy bands of a semiconductor is shown in Figure 51b. Close to absolute zero, the highest valence band 1 is completely filled with electrons. Then comes the forbidden bands, and even higher than that, the free band which is called the conduction band. For the occurrence of electric conductivity, it is essential for a certain number of electrons to move from the forbidden band into the free band where they could be moved under the effect of an electric field. But for moving an electron into the free band, it must be supplied with a certain quantity of energy ΔE necessary for crossing the forbidden band.

The presence of a forbidden band with the "width" of ΔE distinguishes a semiconductor from a metal. In various semiconductors, the value of ΔE is from several tenths to 2ev.* Substances which have a width of a forbidden band is greater than 2ev are called insulators (Figure 51b).

Insulators and semiconductors, at a temperature close to absolute zero, have a very high specific resistance. It would seem that even at room temperature, semiconductors, due to the existence of the forbidden band ΔE , should conduct electricity poorly. In actuality, another picture is observed, and the physical causes of it will be examined below.

For a majority of the semiconductors, ΔE lies within limits of 0.1-1.5ev. From where can the electron gain this energy?

The chief source is the thermal movement of the atoms in the semiconductor substance. At room temperature, the mean thermal energy of a particle is 0.04ev. This is approximately 30-fold less than the amount necessary for transferring the electron to the conduction band. But the problem is that thermal movement is a chaotic process which has a statistical character. In such a process where a colossal quantity of particles is involved, there is always a certain quantity of atoms with a thermal energy of 1.5ev and greater. Such atoms, in colliding with adjacent ones, can transfer to the bonded electrodes their energy which is sufficient for moving them into the conduction band. With an increase in temperature, the thermal movement becomes more intensive, the number of particles with the required energy rises, and at the same time, the number of conduction electrons grows. And, conversely, with a reduction of the temperature, the number of conduction electrons declines, reaching zero at a temperature of -273° .

In addition to this, the amount of electric conductivity is very strongly influenced by the impurities of atoms from other elements. The mechanism of semiconductor electric conductivity is determined chiefly by the extrinsic atoms. In practical terms there are no completely pure semiconductors, and only extrinsic semiconductors are found.

A schematic depiction of the energy structure of an extrinsic semiconductor is shown in Figure 52. In a pure conductor (Figure 52a), the valence band is the supplier of electrons to the conduction band. Here, for transferal to the conduction band, the electrons must increase their energy by ΔE . The extrinsic atoms create energy levels of two types in the semiconductor. Some impurities create energy levels in the forbidden band close to the conduction band, while others also in the forbidden band but here the filled band.

* It must be kept in mind that the expressions "energy levels," "energy bands," "transfer from the forbidden band to the conduction band," and so forth reflect the energy and not the geometric side of the question.

The extrinsic levels of the first type are the supplier of electrons to the conduction band, and for transferring to the conduction band with an extrinsic level the electrons require an energy of ΔE_1 (Figure 52b) which is less than the entire width of the forbidden band. These levels are called the donor levels and the impurities which create such levels are the donor impurities.

The impurities which create energy levels close to the valence band are called acceptor impurities. At a temperature of absolute zero, the acceptor levels are 3. With an increase in temperature, the electrons can transfer either from the filled band into the conduction band or to the free acceptor level, and the probability of the second transfer is significantly greater, since $\Delta E_2 < \Delta E$ (Figure 52c).

If a certain portion of the electrons has transferred from the filled band into the conduction band or to the acceptor levels, then a corresponding quantity of free levels is formed in the filled band and these have been given the name of holes. As a result, the movement of electrons in the filled band becomes possible. Under the effect of an electric field, the electrons can be moved in the opposite direction of the electric field. Here, after their departure they will leave empty spaces or holes, the movement of which is in a direction opposite to the field. The holes in a semiconductor are the equivalent of the positive charge, but in terms of value are equal to the charge of the electron. Thus, the movement of the electrons in the filled band will be represented as the movement of positive charges or holes.

For this reason, in a semiconductor, two mechanisms of conducting can occur: electron and hole. The electron mechanism corresponds to the movement of the electron in the free band, and the hole mechanism to the movement of the electrons (or holes) in the filled band. In semiconductors which do not have impurities, intrinsic conduction is observed caused by the transfer of the electrons from the forbidden band to the conduction band and the movement of holes in the forbidden band.

In accord with the type of conduction, semiconductors are differentiated as intrinsic and extrinsic. The extrinsic ones, in turn, may have a donor impurity (n-semiconductors), an acceptor impurity (p-semiconductor) or impurities which provide mixed conduction.

Having examined the mechanism of conduction in the semiconductor, let us go on to the physical processes for the occurrence of an electromotive force in the semiconductor current sources.

The work of thermal electric generators is based upon the effect of moving the charge carriers (the electrons or the holes) from the hot area of the semiconductor into the cold one.

If one end of an n-semiconductor is heated, then the electrons move from the area with a greater concentration of electrons caused by the warming into the area with a lower concentration. Here electrons will

accumulate on the cold end of the semiconductor, while, respectively, holes will accumulate on the warm end. As a result, a difference of potentials arises on the ends of the semiconductor, and the amount of this difference will be determined by the degree of heat in the hot end and by the properties of the semiconductor material.

An analogous picture is observed in heating one of the ends of a p-conductor, where the holes perform the role of the current carriers. Here the holes which arise during the heating also move to the cold end, increasing its positive charge. Respectively, the negative charge of the heated end increases. A thermoelectromotive force arises.

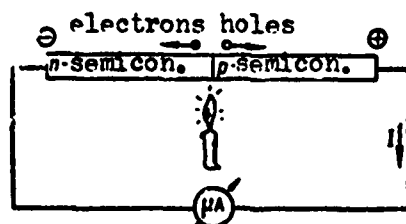


Figure 53. Formation of thermoelectromotive force.

For the semiconductors with intrinsic or mixed conduction, where both the electrons as well as the holes are the carriers of the current, the amount of the thermoelectromotive force is less than in semiconductors with purely electron or purely hole conduction. For this reason, in manufacturing thermal elements, semiconductor couples are used with one of the semiconductors having a donor impurity and the other an acceptor impurity.

A diagram of a thermoelement is shown in Figure 53. In heating the contact point of the two heterogeneous semiconductors, a diffusion of the electrons and holes into the cold areas occurs, and here a difference of potentials arises on the ends of the semiconductor couple. For increasing the output voltage, thermoelements are connected into a battery.

In photoconverters the mechanism for the occurrence of an electromotive force is somewhat different.

The photoelectric source of current is also composed of semiconductors with varying conductions, n and p. Here, on the boundary of the two semiconductors with n- and p- conduction, a so-called p-n junction is formed. In practical terms the p-n junction is created in the semiconductor monocrystal by introducing into one of its areas impurities which create p-conduction and into the other impurities which create n-conduction. The p-n junction formed in this manner represents a barrier which obstructs the movement of the majority current carriers, the electrons and holes, from one area into another. Along both sides of this barrier, positive and negative charges accumulate, and as a consequence of this, a difference of potentials arises in the semiconductor. This difference of potentials creates the conduction current of the minority carriers from one area to another.

In addition, under the effect of the surrounding heat, in the semiconductor, a small number of majority carriers also are able to cross the barrier. As a consequence of these factors, in a darkened semiconductor converter, it is possible to detect a low current. This current has been named the dark conduction current. With a reduction in temperature, the thermal movement of the majority carriers is reduced, and this leads to a reduction of the dark current. However, the conduction current caused by the movement of the minority carriers, under the effect of the difference in the potentials of the p-n junction does not depend upon temperature, and, consequently, will occur.

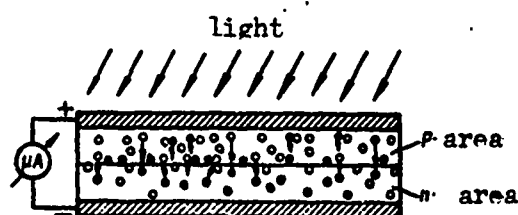


Figure 54. The formation of photoelectromotive force in a semiconductor

With the supply of radiant energy to the semiconductor (Figure 54), the photons, in possessing energy, give it up to the semiconductor atoms, and as a result of this, the atom, in absorbing the photon, loses an electron which become free, and the atom itself, with the loss of an electron, becomes a hole. The electron-hole couples approach the potential barrier, and from here the electrons shift to the n side, while the holes move to the p side. Thus, there arises a movement of positive charges (holes) from the n-semiconductor to the p-semiconductor, and negative charges (free electrons) from the p-semiconductor to the n-semiconductor. A difference of potentials arises on the electrodes of the photocell.

In connecting a photocell to an external circuit, an electric current will flow through it, and the amount of the current depends upon the illumination and the voltage upon the amount of the potential barrier determined by the material of the semiconductor element.

As for the dark current created, as was pointed out above, by the diffusion of a small number of extrinsic electrons in the darkness, in the photoelectric sources of current, it, analogously to the chemical sources of current, plays the role of the polarization emf. The less the amount of dark current, the greater the amount of the photoelectromotive force which can be obtained from the semiconductor photocell with its illumination.

However for creating the electron-hole couple in the semiconductor, the photon's energy should not be less than the energy for breaking the peripheral electron away from its atom. This energy for semiconductors

lies within the limits of 1.1-2.1 ev. The photons of the solar spectrum with a wave length of 0.75 microns (the near infrared area) possess an energy equal to 1.4 ev. Consequently, for using the energy emitted by the sun, it is advisable to employ those semiconductor photo converter the spectral sensitivity maximum of which lies in an area close to radiation with a wave length of 0.75 microns. And the force for breaking the inter-atomic bonds, or, in other words, the width of the forbidden band of the semiconductor should not be greater than 1.4 ev.

The width of the forbidden band is a factor upon which depend the most important characteristics of a semiconductor converter of radiant energy, that is, its photoelectromotive force and efficiency, since for effective conversion it is essential that the p-n junction have a low saturation current. But the saturation current depends upon the intrinsic conduction of the semiconductor, and the smaller the conduction the smaller the saturation current. In turn, the conduction is determined by the width of the forbidden band, that is, the greater the width of the forbidden band, the less the conduction. For this reason, a semiconductor for a photoelectric source should be chosen in such a manner that the width of its forbidden band be maximal, but not exceed the energy of the photon for the given area of the radiant energy spectrum.

Thermoelectric Sources of Current

The thermoelectric sources of current, independently of the origin of the thermal energy powering them, are classified in a large group of thermoelectric generators which include the thermoelectric generators, the thermoemission generators (both vacuum and plasma) and the thermoelectromagnetic generators which are also called magnetohydrodynamic.

The principle of action of a thermal element is based upon the well-known phenomenon of the occurrence of emf in heating the contact points of two conductors from different metals. This was discovered by the German scientist Seebeck in 1822.

In 1834, the Frenchman Peltier established the generation or absorption of heat on the contact point of two different metallic conductors in passing a current through them, and the generation or absorption of the heat occurred depending upon the direction of the current. These phenomena were examined by Thomson who, in 1853, provided a correct explanation to the phenomenon of the thermoelectromotive force and worked out the theoretical prerequisites of thermoelectricity, having established the relationship between the Seebeck and Peltier coefficients:

$$P = \alpha T,$$

where P -- the Peltier coefficient numerically equal to the quantity of heat generated or absorbed in passing a current in the circuit; α -- the Seebeck coefficient establishing the dependency of the thermoelectromotive force upon the materials of the conductors comprising the thermoelement; T -- the temperature according to the Kelvin (Thomson) scale.

However, the thermoelements based on the use of different metals did not find application as a consequence of the low efficiency; and only after the work of Academician A. F. Ioffe who proposed using semiconductors instead of metals as the contact materials, was it possible to raise the efficiency of the thermoelements up to an amount providing the possibility of their application as sources of current.

The semiconductor thermoelement consists of semiconductors with varying conduction, electron and hole. This makes it possible to obtain the maximum thermoelectromotive force since the total emf is formed from the emf of the electrons (negative lead) and hole (positive lead) semiconductors:

$$E = (\alpha_1 + \alpha_2) \Delta T,$$

where α_1 and α_2 -- the coefficient of thermoelectromotive force in microvolt/degree, ΔT -- the temperature difference of the hot and cold junctions.

A thermoelement composed of the semiconductor alloys of bismuth -- tellurium -- antimony (positive lead) and bismuth -- tellurium -- selenium (negative lead) provides for the obtaining of a thermoelectromotive force of around 400 microvolts/degree, at the same time that a thermoelement made by Seebeck was the copper-bismuth couple developed only around 70 microvolt/degree.

The efficiency of a thermoelement is determined by the formula:

$$\eta = \frac{\alpha^2 \sigma}{\chi} \Delta T,$$

where σ and α -- the already known coefficient for thermoelectromotive force and electric conductivity, while χ -- the coefficient of thermal conductivity.

From the given formula, it follows that a material can possess a high efficiency if the coefficient of the thermoelectromotive force and specific electric conductivity are high, while the coefficient of thermal conductivity is low. For metals this ratio is unfavorable, since metals, in possessing an insignificant α and a large χ , cannot provide an efficiency of greater than 1.5-2 percent.

Semiconductors have a better ratio between the designated values, that is, a comparatively large α and a low thermal conductivity. In truth, with all the seemingly good conditions in the semiconductors there is a relationship between the specific electric conductivity σ and the coefficient of the thermoelectromotive force when with a high α it is not possible to provide a sufficient amount of σ .

The ratio $\frac{\alpha^2 \sigma}{\kappa}$

is designated by the letter Z which, in semiconductor technology, has been named the quality coefficient of the semiconductor material.

The quality coefficient for various semiconductor alloys has a maximum value only in a certain temperature interval, as a consequence of which, in making up a thermoelement, it is essential to consider the conditions under which each lead will be used.

Since the voltage of a thermoelement is low and for individual types lies within limits of 0.05-0.15 volts, the thermoelements are connected into series and parallel groups and form a thermopile. The thermoelectric battery with a source of heat forms a thermoelectric generator with definite output parameters such as output power, voltage and limiting current.

The prototype of the modern complicated atomic thermoelectric generators was the humble "Partisan Pot" developed by Academician A. F. Ioffe and his co-workers during the years of the Great Patriotic War. This pot in the bottom of which was a thermopile heated by the fire and filled with water for cooling the cold junctions worked well for the signal troops of the partisan detachments and combined units, supplying power for their radio sets during any weather or time of day. Series output of the world's first TG-1 thermoelectric generators for powering military radio receivers and transmitters began in 1943 in the Soviet Union.

During the postwar years, the co-workers at the Semiconductor Institute of the USSR Academy of Sciences developed industrial models of the thermoelectric generators. These were the TKG-3, TEGK-2-2 and TKG-10 which have been widely used in areas not having electric power. The TKG-3, TEGK-2-2 and TKG-10 thermoelectric generators are designed for powering radio receivers and small kolkhoz radio sets of the KRU-2 type.

The thermoelectric generators for powering radios differ in terms of design and output parameters. The thermoelectric generator (Figure 55) consists of a heat transmitter 1, on the sides of which are fastened the sections of the thermopile 2. The cold junctions 3 of the thermopile have been extended on aluminum ribs 4 which are radiators for dispersing the heat. Each section of the battery consists of several series connected thermoelements. The heating of the hot junctions of the thermopile is carried out with the heat emitted from a kerosene burner.

The TKG-3 thermoelectric generator with a power of 3 watts has the lowest power of the family of thermoelectric generators for powering radios. It has 2 thermopiles, one of which with a voltage of 2 volts and a current of 2 amps is designed for powering the vibrating-reed converter of the anode circuit of radio tubes, while others with a voltage of 2 volts and a current of 0.5 amps powers the filament circuits.

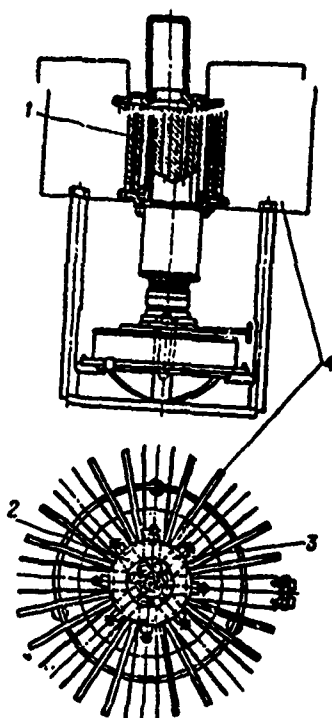


Figure 55. The TKG-10 thermoelectric generator:
1 -- heat transmitter; 2 -- sections of thermopile;
3 -- cold junctions of thermopile; 4 -- radiators.

1 amp for producing voltage to power the anode circuit of the tubes in the KRU-2 radio sets. The TKG-10 thermopile is heated by a special kerosene burner consuming around 100 grams of kerosene per hour of use. The load characteristics of the TKG-10 thermoelectric generator are given in Figure 57.

It must be pointed out that the use of vibrating reed converters in the TKG-3 and TKG-10 thermoelectric generators for obtaining the power for the anode circuit of the radio tubes is an obsolete solution. The recently developed transistorized voltage converters can completely replace the obsolete vibrating reed converters which are a source of additional interference and possess a low conversion ratio.

Another type of thermoelectric generator, the TEGK-2-2, with a power of 4 watts also has 2 thermopiles: 1 low-volt for powering the filament circuits with a voltage of 1.4 and 0.6 volts and a current of 180 and 650 milliamps respectively, and another high-volt one with a voltage of 150 and 60 volts and current of 5 and 13.5 milliamps of the anode circuit. The thermopile is heated with the 20-line Molniya kerosene lamp consuming 60-70 grams of kerosene per hour of use. The TKG-3 and TEGK-2-2 thermoelectric generators, with an overall coefficient for the conversion of thermoenergy into electric of 0.75 percent, weigh eight kilograms. The load characteristics of the TEGK-2-2 thermoelectric generator are given in Figure 56.

The development of the TKG-10 thermoelectric generator with a power of 10-12 watts was a step ahead. Each thermoelement of this generator provides a voltage of around 55 millowatts with a temperature difference of 300° centigrade between the hot and cold junctions. The efficiency of the TKG-10 is 3.5 percent. Like the other thermoelectric generators, the TKG-10 has a filament thermopile with a voltage of 1.2 volts with a current of 0.7 amps and a thermopile for powering a vibrating-reed converter with a voltage of 10 amps and a current of

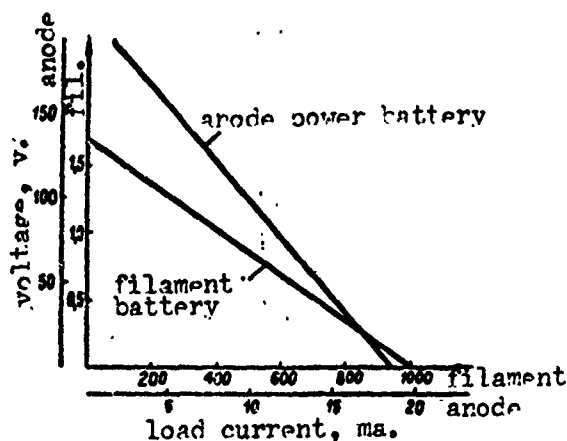


Figure 56. Load characteristics of the TEGK-2-2.

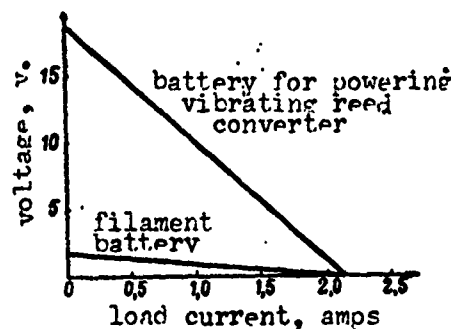


Figure 57. Load characteristics of the TEGK-10.

The above-described thermoelectric generators have batteries composed of thermoelements with an operating temperature of up to 300° centigrade, that is, of low-temperature semiconductor thermoelectric substances. Regardless of the comparatively simple design and the simple solution to such problems as the dissipation of heat, the thermoelectric generators using low-temperature thermoelements have a low efficiency and this is their basic drawback. For this reason, the use of medium-temperature and high-temperature thermoelements has attracted the close attention of designers as a consequence of the possibility of significantly raising the efficiency of the thermoelectric generators with a temperature of $300-700^{\circ}$ centigrade for the hot junctions (medium-temperature thermoelements) and $700-1500^{\circ}$ centigrade (high-temperature thermoelements).

A. N. Voronin and co-workers have developed a new type of thermoelectric generator operating on a natural fuel. The new TEG-50 thermoelectric generator provides an output of 50 watts with a voltage of 8 volts. The consumption of natural gas is 0.8 cubic meters per hour. A complex of thermoelectric generators has also been developed designed for a power of 300 watts and heated by a burner using natural gas. Analogous low-power thermoelectric generators are produced in the U.S. in the form of portable units weighing 5 kilograms and operated from a tank of propane.

Of great interest are the thermoelectric generators using the energy of the sun for heating the junction of the thermopile. As is known, each square meter of the earth's surface which is perpendicular to the sun rays receives around 1 kilowatt of energy, and for this reason, the utilization of solar energy is of great national economic significance, and the

use of thermoelectric converters, along with other devices, has definite prospects.

In the USSR and abroad, solar thermoelectric generators have been developed with a power of from several watts to a kilowatt. Among the numerous designs of thermoelectric generators using solar energy, an interesting solution to the concentration of energy and heat dissipation in a single design element has been found by A. N. Voronin who proposed using small parabolic reflectors (see Figure 58). Here the energy of the sun rays is concentrated by a parabolic reflector similar to the reflector of a car headlight on a thermoelement, and the cold junctions of the thermoelement have a thermal contact with the reflector itself which, in the given instance, performs the role of a radiator for discharging the heat from the cold junctions into the surrounding space.

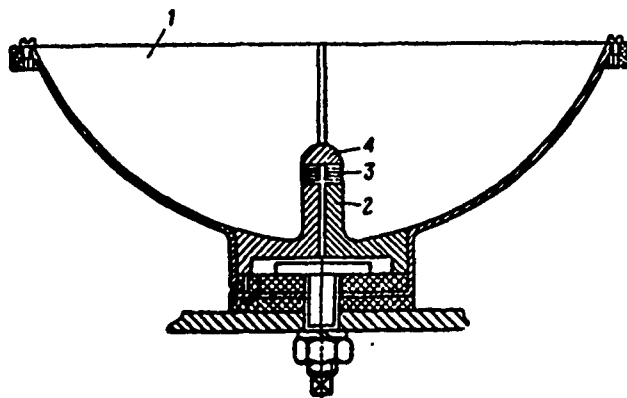


Figure 58. The heliothermoelectric generator of A. N. Voronin; 1 -- parabolic reflector; 2 -- heat and conductor; 3 -- heat receiver.

At present, the efforts of scientists and engineers have been concentrated on developing thermoelectric generators using various radioactive elements as the heat source. The interest shown in such generators is explained by the necessity of creating a source of current which will operate for a long period of time without replenishing the materials consumed in the process of use.

The first device of such a sort was the Beta-1 atomic power plant developed by Soviet scientists and engineers. This was a thermoelectric generator using low temperature thermoelements and powered from the heat generated by the radioactive isotope of cerium-144. The Beta-1 atomic thermoelectric generator supplies the power for an automatic weather station.

Somewhat after the publishing of data on the Beta-1 plants, the foreign press announced the development of a number of atomic thermoelectric generators in the U.S. using low-temperature thermoelements of the SNAP type and which were to be used basically for powering the equipment of various types of artificial earth satellites and beacons.

A major step ahead in developing an atomic thermoelectric generator operating on high temperature thermoelements was (also for the first time in world technology) the development by Soviet scientists of the Romashka nuclear thermoelectric station with a power of 0.5-0.8 kilowatts using silicon-germanium thermoelements and designed for operating at a temperature of around 1000° for the hot junctions. The thermopile of the Romashka generator produces a current of 88 amps.

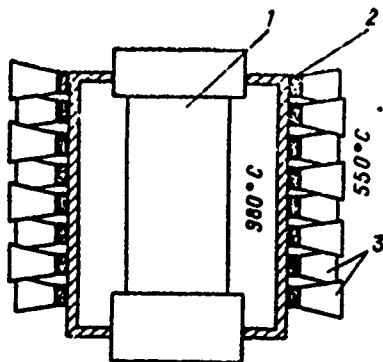


Figure 59. Design of the Romashka converter:

1 -- cylinder of reactor with neutron reflector; 2 -- thermoelements; 3 -- heat-emitting radiators.

A schematic diagram of the atomic electric generator is shown in Figure 59. The reaction zone of the Romashka unit consists of a graphite cylinder with uranium dicarbide and a beryllium reflector capable of withstanding a high temperature. The Romashka atomic reactor develops a power of 40 kilowatts with a temperature of around 1900° in the reaction zone. The cold junctions of the thermopile are connected to a system of radiators which disperse the heat into the surrounding space. The temperature of the cold junctions of the Romashka atomic electric generator reaches 600° centigrade.

The best models of the thermoelements being manufactured at present possess an efficiency of around 10 percent. For the semiconductor thermoelements, the theoretically possible limit is felt to be an efficiency of 25-30 percent, and here one understands the efficiency of the thermoelement themselves, since the efficiency of the thermoelectric generators operating on conventional fuel does not exceed 5 percent. The reason for such a discrepancy is the large amount of heat energy losses. For this reason, the highest efficiency will obviously be able to be reached in the nuclear thermoelectric generators where the utilization factor of the heat energy is significantly higher.

The prospect for raising the efficiency of thermoelements consist in developing semiconductor substances with a high Z quality coefficient, in particular, liquid semiconductor thermoelements and high temperature semiconductor materials.

Photoelectric Sources of Current

Photoelectric sources of current are direct converters of solar energy into electrical energy, and in this manner they differ from the solar thermoelectric batteries which convert solar energy into electric energy through the intermediate process of concentrating the energy of the sun in thermal energy.

The development of the photoelectric current sources which at present are an independent sector of science and industrial production was proceeded by extensive research and technical search in the area of obtaining materials which would provide for the optimum characteristics of the converter in terms of efficiency, spectral sensitivity and output characteristics, that is, voltage and tolerable current density.

As was pointed out at the beginning of this chapter, the photocells with a barrier layer, or as they have come to be called, the barrier-layer photocells, are most suitable as converters of the energy from the light radiation into electric energy. The barrier-layer photocells comprise a rather large group among the semiconductor converters, however only a few of them have turned out to be suitable for practical use. One of the conditions of suitability for any semiconductor for use as a photoconverter is its spectral sensitivity. Figure 60 gives the spectral sensitivity curves of various photoconverters and the curve for the sun's spectral radiation.

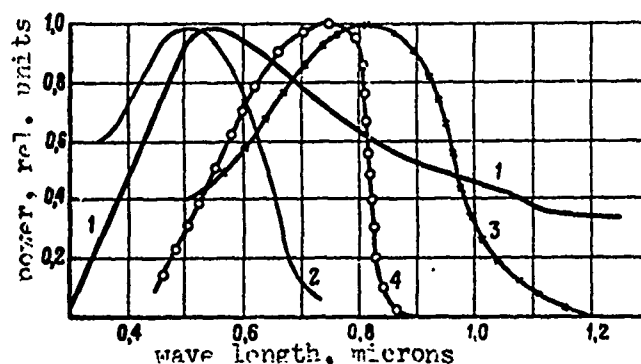


Figure 60. Spectrum of solar radiation (1) and spectral characteristics of photoconverters: 2 -- selenium; 3 -- silicon (monocrystalline); 4 -- cadmium telluride film.

Since the energy emitted by the sun is the source of energy for the photoconverters, the photoconverters are chosen having a spectral sensitivity conforming to the curve for the spectral distribution of solar energy. However, in addition to the required spectral sensitivity, the photoconverter should possess the necessary efficiency. For example, the long-known selenium photocells, the spectral sensitivity of which conforms well to the spectrum of solar radiation, are not suitable for use as power converters of solar energy into electrical energy as a consequence of the extremely low efficiency (0.1 percent), although they do find wide use in devices such as photographic exposure meters, and so forth.

In choosing the materials for the photoconverters, great attention has been paid to the monocrystal of silicon and germanium with the artificially created p-n junction, the properties of which promised achieving the necessary characteristics. However, it turned out subsequently that

the characteristics of the germanium photoconverters were lower than the silicon ones, and this is explained by the greater width of the forbidden band in the silicon than in the germanium as well as in selenium.

Theoretically, barrier-layer photoconverters can have 100 percent efficiency under the condition of radiating them with a light the wave length of which conforms to the maximum of the spectral sensitivity of the given photocell (Figure 60). Here, all the radiant energy falling on the photocell should be absorbed by the p-n junction under the condition that the current in the photocell conforms to the number of electron-hole couples arising in the same time interval, and its internal resistance, from infinitely large in darkness, becomes infinitely small in illumination.

But in nature there are no photocells which satisfy the above-given conditions. First of all, the spectral sensitivity of a majority of photoelectric converters lies in an area of wave lengths of 0.6-1.0 microns, that is, the yellow and red rays and the adjacent infrared rays. As for solar radiation, the energy in the spectral range from 0.6 to 1.0 microns is around 40 percent of the total energy emitted by the sun. For this reason, the very discrepancy of spectral characteristics makes it impossible to obtain a converter efficiency of more than 40 percent.

Moreover, the process of converting the photons into electron-hole couples in the semiconductor is accompanied by various losses both of the energy of the photons themselves in the body of the semiconductor, as well as the energy of the newly formed electrons and holes in surmounting the resistance of the electron and hole portions of the semiconductor. A significant portion of the losses is made up from a passage of solar radiation through the surface of the photocell due to reflection and absorption in the surface layer.

These factors prevent the obtaining of photoelectric converters with an efficiency of more than 14 percent which would be considered the maximum possible limit for the semiconductor converters.

At present, the silicon solar converter is the basic photoelectric source of current which has a comparatively broad use.

The design of a silicon photoconverter is shown in Figure 61. The silicon photoconverter is manufactured from a monocrystal of pure silicon by holding it at a high temperature in the presence of gaseous boron. As a result of such processing, the surface layer of the silicon plate is converted into silicon with p-conductivity, while at the same time, the interior portion of the plate remains in the initial state with n-conductivity. A certain distance away from the surface of the heated plate the p-n junction forms. After the removal of the layer with the unnecessary type of conductivity from the surface of the plate, a semiconductor photoconverter is formed, the external portions of which have a p-conductivity and a n-conductivity, and in the middle of the body there is the p-n junction. A current drain is connected to the surface from the p-silicon. A

similar drain is formed with the layer from n-silicon. As the current drains ordinarily sprayed-on fine films of silver or nickel are used. The finished cell is packed in a sealed film casing which protects the current drains and the sensitive layer from the effect of atmospheric precipitation and mechanical injury.

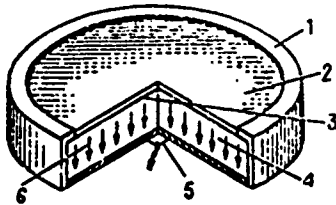


Figure 61. Disc-type silicon photocell.
1 -- current drain from layer with n-conductivity (negative hole); 2 -- silicon layer with n-conductivity; 3 -- p-n junction; 4 -- silicon layer with p-conductivity; 5 -- current drain from layer with p-conductivity (positive hole); 6 -- movement of current carriers in p-layer.

The silicon photoconverter of the above-given design has the following basic characteristics: emf 0.5-0.55 volts, voltage 0.4 volts, short circuit current 20-30 milliamperes per square meter of area, efficiency 8-11 percent.

The silicon solar photoconverters produced by Soviet industry have the following basic characteristics given in Table 21.

Table 21

Silicon Photoconverters

type of photo-converter	dimensions mm	working surface, cm ²	Average effc., %	output current, ma	output power, mw	voltage, v	surface temp., °C.	solar rad. energy, mw/cm ²
FKD								
ΦKД-2	10×10	0.83	8	13	7.2	0.4	30	100
ΦKД-3	10×15	1.275	8	27	10.8	0.4	30	100
ΦKД-4	10×20	1.7	8	36	14.4	0.4	30	100
ΦKД-5	10×30	2.4	8	50	20.0	0.4	30	100

As follows from Table 21, the voltage of the silicon photocells does not depend upon the active area and is a constant, in contrast to the output current and power, the amount of which is proportional to the active surface of the photocell.

Solar batteries with an area from one square decimeter to one square meter are assembled from the individual cells by their series and parallel connection. The form and dimensions of the solar batteries vary depending upon the purpose.

In connecting individual photocells into a battery, it is essential to consider the amount of the optimum load of the photocell, since the optimum load depends upon the area of the photocell. Thus, for a photocell with an area of 0.7 square centimeters, the optimum load resistance is 3.3 ohms, and 8.5 ohms for a photocell with an area of 2.1 square centimeters.

The individual photocells are connected into a battery either by using special buses or by overlapping, and in the latter instance, the active surface of the battery is reduced to the overlapping of the photocells. The connecting of a conventional storage battery as a buffer to the solar battery can be effected by using a germanium or silicon junction diode having a minimum resistance in the forward direction and sufficient power calculated to pass the required amount of charge current.

The characteristics of the silicon photoconverters depend upon the amount of illumination and temperature. Thus, with a 900 percent increase in radiation, the short circuit current of a silicon photocell also increases by almost 900 percent. However, the output of a solar battery, with an increase in illumination, rises to a certain limit, since the amount of the optimum load resistance is reduced here. For this reason, the fluctuations of the light flux within limits of 15-20 percent have virtually no effect on the output of the battery. The efficiency of the silicon batteries also virtually remains unchanged with a fluctuation in illumination. Thus, for example, a change in radiation from 1000 to 100 watts per square centimeter causes a reduction in the efficiency from 10 to 7 percent.

At the same time, the silicon batteries, like any other photoelectric source of current, require optimum illumination for obtaining maximum efficiency from them. The choice of this illumination is made depending upon a number of factors and primarily upon temperature. It has been established that with an increase in radiation up to 150-fold, output increases by only 20-30-fold. Here, it is not recommended that solar radiation be increased more than 5 watts per square centimeter, since here the output will not rise. The normal radiation at which the silicon batteries operate stably is felt to be a flux of around 0.1 watts per square centimeter.

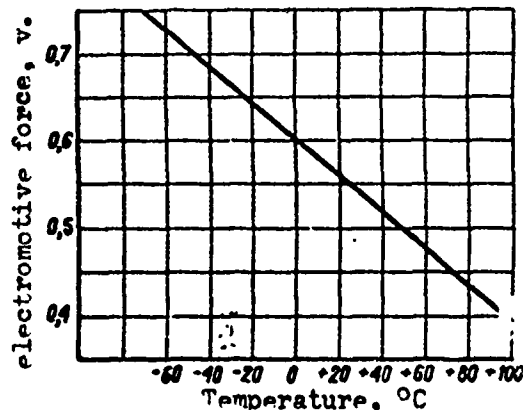


Figure 62. Dependency graph of emf of silicon photocell upon temperature.

The influence of temperature on the performance of silicon photoconverters tells, primarily, on the change in the emf, since the amount of the temperature coefficient is $2 \cdot 10^{-3} \text{ V/}^\circ\text{C}$. Thus, with a change in the temperature of the silicon photocells from -60° to $+100^\circ$ centigrade, its emf falls from 0.7 to 0.4 volts (Figure 62). Here, we can observe a corresponding decline in the emf, the amount of which, with a change in temperature by 150° , declines by almost 100 percent. Nevertheless, a temperature of from

-65° to +175° centigrade is the temperature limit for the operability of the silicon converters.

In considering that solar batteries require a radiation flux of around 0.1 watt per square centimeter for normal use, and this occurs only with a cloudless sky during sunny weather, the use of the solar photo converters in cloudy weather does not provide the proper effect. For this reason, the greatest effect from the use of silicon solar batteries can be obtained in operating the photogenerators in the southern regions of our nation, where the quantity of sunny days during the year reaches 80 percent, while in the central regions, the number of cloudless days is only 25-45 percent.

Per square meter of the earth's surface perpendicular to the flux of sun rays there is around 1 kilowatt of solar energy. If we take the efficiency of modern solar batteries as equal to 8 percent, then for lighting a small house it would be sufficient to place a solar battery with an active surface of 3-4 square meters on the roof. Such a battery during the daytime could develop a power of 250-300 watts, and this is sufficient for powering electric appliances of low power and for charging storage batteries to light the rooms during the nighttime.

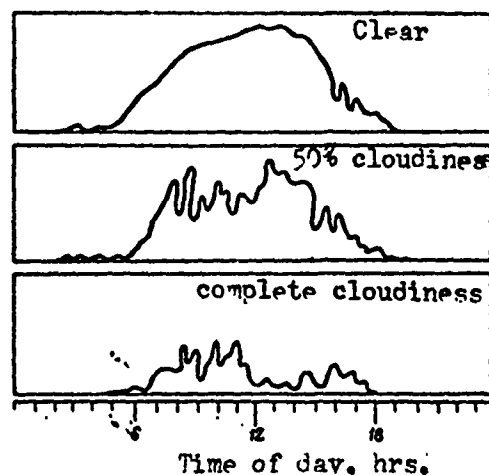


Figure 63. Daily course of change in the power of solar radiation.

The graph of Figure 63 gives the amount of daily changes in the power of solar radiation falling on 1 square meter of the earth's surface located perpendicular to the sun. As can be seen from the graph, the level of solar energy on a cloudy day is around one-quarter of the flux in clear weather. The graph of Figure 64 depicts the curves for the change in solar illumination during the year in the northern, central and southern regions of the USSR.

From the data given in the graphs of Figures 63 and 64, it follows that in a number of instances, for providing effective use of the photo-

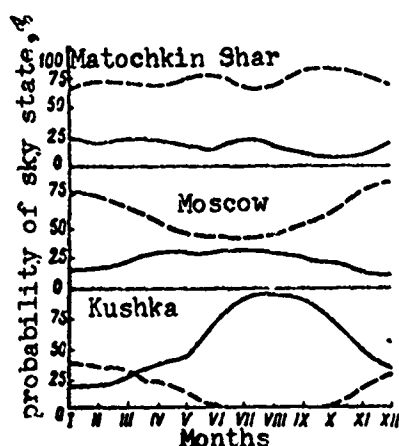


Figure 64. Curves of solar active-ness at various latitudes during the year: broken curve -- cloudy; solid -- clear.

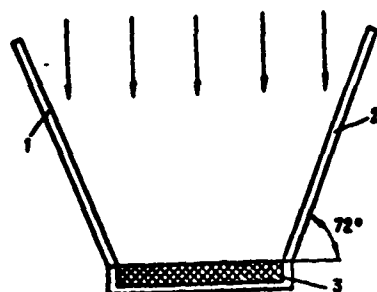


Figure 65. Solar concentrater for silicon photoconverters: 1 and 2 -- mirrors; 3 -- photo-converter.

addition, the solar battery during the sunny weather should charge the 7D-0.1 buffer storage battery. For this reason, the operating current of the solar battery should be calculated for 22 milliamps, since 12 milliamps are necessary for charging the 7D-0.1 battery. The most suitable in terms of current are the FKD-3 cells which, considering the overlapping of the working surface, provide the necessary current of 22 milliamps. However, for charging the 7D-0.1 storage battery, a charging voltage of 10.5 volts is needed. As a consequence of this, the number of FKD-3 cells in a series

electric sources of current, it is essential to use solar radiation concentraters in the form of mirrors or converging lenses. One of the types of concentraters used for the solar photoelectric station of the VNIIT [All-Union Scientific Research Institute for Sources of Current] is shown in Figure 65. But the concentraters, along with increasing the effective work of the unit, have an essential drawback consisting the the necessity of a sun-tracking system during the daily rotation of the earth. Here the solar radiation concentraters should not lead to the overheating of the silicon solar batteries, considering that the upper operating temperature for them is $+175^{\circ}\text{C}$.

As was pointed out above, for providing the continuous use of equipment powered by solar batteries, it is essential to connect in parallel a storage battery so that during cloudy weather or at night the equipment would be powered from the storage batteries.

As an example, let us give the approximate calculation of a solar battery for operating an Almaz transistorized radio receiver with a 7D-0.1 storage battery with a voltage of 9 volts.

Under receiving conditions, the Almaz consumes a power of around 90 milliwatts at a current of 10 milliamps. For powering the receiver during sunny weather, a solar battery with a voltage of 9 volts is required. This battery is made up from silicon photocells in a quantity of $9:0.42 = 22$ cells. In

connection should be increased to 27. The total area of the solar battery comprised of 27 FKD-3 cells will equal 40 square centimeters. This makes it possible to attach the battery to the top of the Almaz receiver (134 x 35 mm).

The advantages of such a combined method for powering the equipment operating under field conditions are obvious.

The examples of the silicon solar batteries exhibited at the USSR Exhibition of National Economic Achievements consisted of 12 and 19 cells connected in series. The first battery produces a current of 20 milliamps with a voltage of 5 volts, and the second, 40 milliamps at a voltage of 7 volts. Another type of battery also shown at the exhibition is designed for geological equipment and consists of several sheets with solar batteries, the total power of which is 100 watts.

The photoelectric station developed for the first time in our nation for powering a Kama pump consists of 3 panels 1 x 5 meters in size on which solar batteries have been placed in the form of 10 strips 30 mm wide with concentrators (Fig. 65). The active area of the battery is 3.6 sq. meters.

The optimum power of the unit with a flux of solar radiation of 310 watts per square meter is 248 watts with a voltage of 45 volts. Since the unit was built for experimental work, and did not aim at obtaining the maximum possible output characteristics, its solar batteries were assembled from silicon photocells with a low efficiency of 3-3.5 percent. The total efficiency of the unit, considering the consumption for power for the solar tracking device, was 2.6 percent.

Of the foreign models of photoelectric generators, we should mention the solar batteries produced in the U. S. for powering transistorized radio receivers. One such battery consists of 32 silicon cells with an effective surface of 60 square centimeters. This provides a voltage of 9 volts with a current of 15 milliamps. Another solar unit is designed for charging storage batteries with a voltage of 12 volts and consists of two plates with a total area of 400 square centimeters. The unit weighs 400 grams.

A silicon solar battery produced by one of the Japanese firms is designed to operate in wristwatches in a buffer with a sealed cadmium-nickel storage cell with a capacitance of 0.1 amps per hour. With a full charge of the KN storage cell, the watch can operate for 6 months without additional illumination. A light flux of 250 lumen for four hours is sufficient in order to operate the watch for one day.

In the foreign press it has been announced that solar batteries have been located in the helmet of a soldier for powering a field radio set, on glasses for powering hearing aids, and so forth.

However, according to the calculations of foreign economists, the use of solar batteries for powering household radioelectronic equipment

and as power packs in a household at present is economically disadvantageous, since the cost of one watt-hour of energy obtained from the photoconverters is \$10. This is explained primarily by the high cost of producing the silicon cells.

For this reason, the silicon solar batteries have gained the widest use in equipment for space research. At present it would be difficult to name any space equipment both in our nation and abroad which would not have silicon photoelectric batteries onboard.

Recently, new photoconverters have been developed. These are called film converters, in contrast to silicon ones, and they are manufactured from the monocrystals of pure silicon. The film converters are thin films from semiconductor materials such as cadmium sulfide, cadmium telluride and gallium arsenide sprayed onto glass with a metal base playing the role of the current drain. After the spraying, the operation of creating a p-n junction in the film is carried out.

The specific power of the film converters is around 120 watts per kilogram, while the specific power of the silicon converters does not exceed 45 watts per kilogram.

The film converters can have a surface up to 100 square centimeters while the silicon ones are restricted to the dimensions of the silicon monocrystal, that is 25 x 12 x 1 mm.

It is estimated that the cost of the film photoconverters will be approximately 900 percent less than the silicon ones, however, with all the positive qualities, the film converters possess a substantial drawback, namely the low efficiency, the amount of which varies within limits of 3-5 percent (with the exception of the converters from gallium arsenide).

The basic characteristics of the presently existing film photoconverters are given Table 22.

Table 22

Film Photoconverters

Name of material of photoconverters	Emf open circuit voltage, volts	Short circuit current, milliamps/sq cm	Efficiency, percent
Cadmium telluride	0.4-0.57	6-14	3.5
Cadmium sulfide	0.4-0.5	10-15	approx. 3
Silicon with p-n junction on Cu ₂ S film	0.25-0.3	5-7	approx. 3
Gallium arsenide	0.8-0.9	--	12-14

The dependency of the emf upon temperature in the film converters is significantly less expressed than in the silicon monocrystalline ones.

Thermoemission (Plasma) Sources of Current

In 1949, A. F. Ioffe proposed using the phenomenon of thermoionic emission for creating vacuum thermoelements which, in contrast to the solid-state semiconductor thermoelements, would have a contact between the cold and hot junctions. In a thermoemission cell, the hot and cold ends are separated by a space which does not conduct heat or conducts it poorly, as a consequence of which the losses in such a converter are reduced to a minimum.

In the simplest form, the thermoemission converter is a vacuum or gas-filled vessel with a cathode and anode (Figure 66).

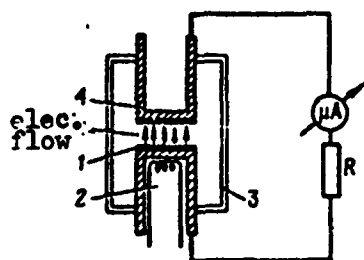


Figure 66. Principle of action of plasma converter:
1 -- cathode; 2 -- heater; 3 -- vacuum cylinder; 4 -- anode

The material of the cathode and anode of a thermoemission cell is chosen in such a manner that the work expended on providing the escape of the electron (the work function) from the anode is less than the work function of the cathode. In heating the cathode, it emits electrons which, in striking the anode, supply it with their energy, and a portion of this energy is consumed for heating the anode (energy losses), while a portion goes to the external circuit, where the useful work is performed.

In a thermoemission converter, the cathode is made from the refractory material of tungsten and is plated with a layer from elements possessing a high emission capacity such as cesium, thorium or barium. The anode is manufactured from cesium with a silver or barium oxide in such a manner that the work function is less than the work function of the cathode materials. The space charge which is formed with the escape of the electrons from the cathode is eliminated by using the cesium vapors which fill the vessel of the converter. With a collision of the electrons which form the space charge with the cesium atoms, a plasma is obtained the current of which is directed from the cathode to the anode. Simultaneously, the cesium vapors reduce the work function of the cathode and the anode, and this raises the overall effectiveness of the converter.

The thermoemission electric generators can be divided into three basic groups: gas-filled, vacuum and plasma. According to the working temperature of the cathode, the emission converters are divided into low-temperature with a cathode temperature of 900° - 1300° , medium-temperature with a cathode temperature of 1600 and 1900° and high-temperature with 2300 - 2700° .

The low temperature converters have a cathode of metal or a semiconductor covered with a film from an alkaline or alkaline earth metal which is

the electron supplier. The plasma converter with a cathode of tungsten and covered with a film of barium operates at a temperature of 1300° centigrade. Its output voltage is 0.7 volts with an efficiency of around 5 percent. Another converter with a tungsten cathode with a cesium film operating at a temperature of 1600° centigrade has an output voltage of 0.8 volts and an efficiency of 9 percent. The same converter at a temperature of 1100° centigrade provides a voltage of 0.7 volts with an efficiency of 5 percent.

The medium-temperature converters have the same tungsten base as the cathode materials with a film of silicon bicarbide. At a temperature of 1900° centigrade, such a source of current develops a voltage of 1.1 volts with an efficiency of 10-15 percent. A cathode of uranium and thorium carbide at a temperature of 2300° centigrade makes it possible to bring the efficiency of the converter up to 15 percent. Such a cathode is also interesting for the fact that in the event of using it, there is no necessity of heating the cathode, since the generation of heat occurs from the splitting of the uranium nucleus.

The cathode base of the high temperature converters is manufactured from tantalum or tungsten. The free space is filled with cesium vapors. In one of the models of a high temperature converter, it was possible to obtain an efficiency of around 10 percent with a voltage of 2.5 volts.

The above-listed types of thermoionic converters are vacuum ones and differ from the gas-filled ones in the small interelectron space which in a majority of designs does not exceed 10 microns.

The gas-filled converters use xenon or argon as the gas in addition to mercury vapors in a mixture with one of the noble gases. The cathode base of such converters consists of tantalum while the metallic anode is plated with a film of barium oxide. With the first starting of the converter, a voltage is applied to it, but after an arc is formed, this voltage is shut off and the arc discharge is maintained by the difference of the potentials between the anode and cathode. The output voltage of certain gas-filled TEG [thermoionic generator] is 0.7 volts with an efficiency of around 0.3 percent, although the actual efficiency can be brought up to 25 percent and more.

In design terms, the gas-filled thermoemission generators are simpler than the vacuum ones, since the clearance between their electrodes can be 1 mm and more. There are rather many different types of generators, including generators making it possible to obtain alternating current. This is particularly important for powering units designed for a varying amount of voltage.

The third type of thermoemission electric generators is the plasma generators. In contrast to the gas-filled and vacuum ones, these possess a high degree of ionization of the interelectrode space with a very high temperature of the ionized electron gas, reaching several thousand degrees. The presence, in the interelectrode space, of a plasma the temperature of

which can be as high as one wishes provides a rather high efficiency of the plasma generator, and the voltage of a plasma generator can reach 10 volts and more, while the voltage of the vacuum and gas-filled generators does not exceed 0.8-1.2 volts.

The high electric conductivity σ , the high coefficient of the thermoelectromotive force α and the low coefficient of thermal conductivity λ show that the plasma is an ideal semiconductor making it possible to obtain a very high efficiency. Another positive quality of the plasma is the absence of a dependency of output voltage upon temperature, as occurs in the solid-state semiconductor elements.

One of the questions in the practical realization of the thermo-emission electric generators is the method of heating the cathode. The use of any burners with conventional chemical fuel is ill-advised for the same reasons as for the thermoelectric generators, that is, as a consequence of the great losses in radiation and the impossibility of obtaining a high temperature.

These drawbacks can be eliminated by using nuclear materials as the fuel. These materials include uranium carbide and others and some of these materials can simultaneously perform the function of the cathode. This significantly simplifies the design of the burner and a significant reduction in size and weight is achieved. A schematic depiction of a thermoionic generator with a nuclear cathode is given in Figure 67.

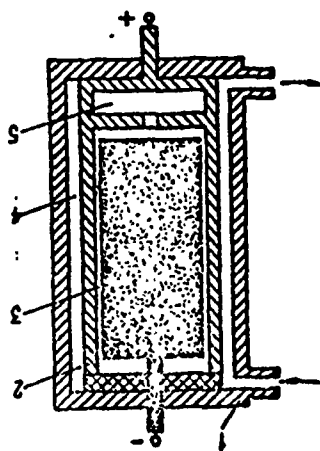


Figure 67. Diagram of a thermoionic converter with a nuclear source of heat;

- 1 -- protective jacket; 2 -- anode;
- 3 -- cathode of uranium carbide, UC;
- 4 -- space for cooling agent;
- 5 -- chamber with cesium vapors.

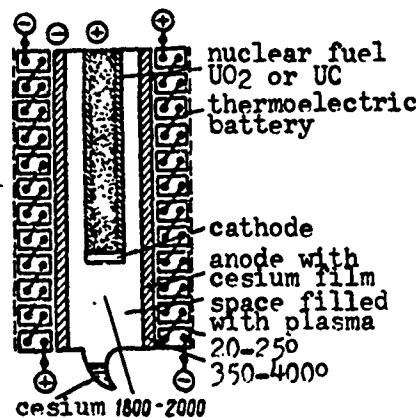


Figure 68. Combined thermoionic (plasma) and thermoelectric converter.

The thermoionic nuclear-fuel generator developed in the U.S., with a cathode temperature of 2000° and an anode temperature of 1400° , produces a power of 100 watts for the external circuit with an efficiency of 12 percent. One such generator is made in the form of a cylinder with a diameter of 25 mm and a length of around 300 mm.

For the purposes of raising efficiency, the design of a double-casing converter has been proposed (Figure 68). In addition to providing for the work of a thermoionic generator from the nuclear fuel, use is also made of the heat generated on the walls for heating the thermoelements located along the perimeter of the cylinder. This makes it possible to raise the specific power of the converter. Such a converter has been proposed for use as an on-board source of current on space ships.

Among the drawbacks of the thermoionic generators is the low output voltage with a very great current density. Thus, for a majority of the generators with a power of 1 kilowatt, the output current is 1000 amps with a voltage of 1 volt.

The foreign press has announced that the General Electric firm has produced a modular thermoionic generator with dimensions close to the dimensions of a metal ruble and weighing around 85 grams. The efficiency of the generator is 2.5 percent, the operating cathode temperature is 1100° and 600° for the anode, and the output of the generator is 1 watt.

There are interesting prospects for using the thermoemission converters in applied solar energy. The solar thermoemission converters with organized series production possibly will be the most profitable of all the presently existing solar generators.

The thermoemission solar converter, as a consequence of the necessity to maintain a cathode temperature on the order of $1700-1800^{\circ}$ centigrade which can be achieved with a power density of around 20 watts per square centimeter, should have a solar energy concentrator with a concentration factor of several thousand (since the density of solar radiation on the surface of the earth is, as was pointed out above, 0.08-0.1 watts per square centimeter). A parabolic mirror with a diameter of around 3 meters could serve as such a concentrator.

The existing designs of the thermoemission converters possess an efficiency up to 15 percent with a power density of 20-30 watts per square centimeter. In solar units it is possible to expect the obtaining of a density of 7-12 watts per square centimeter, that is, with a flux of solar energy of 800 watts per square meter, the efficiency of a solar thermoemission converter to reach the significant amount of 11 percent. An efficiency of 7.5 percent for the solar units with thermoemission converters must be considered realistic and completely feasible at present, considering the consumption of power on focusing the unit toward the sun and on cooling. This significantly exceeds the efficiency of units having silicon converters.

Thermophotovoltaic Converters

In the above-given sections where the thermoelectric and photoelectric sources of current were described, it was mentioned that the converters of these types have an insufficient efficiency and this restricts their use. In addition, the output characteristics of the solar thermal and photoconverters to a significant degree depend upon the density of the flux of solar radiation. The amount of this flux at ground level is significantly less than outside of the atmosphere, while the constant fluctuations of illumination caused by the weather require the buffering with storage batteries. This is not always feasible in terms of operating conditions. For this reason we can clearly understand the interest shown recently in the thermophotovoltaic converters which can have a higher efficiency and better weight characteristics than the thermoelectric or thermoemission ones.

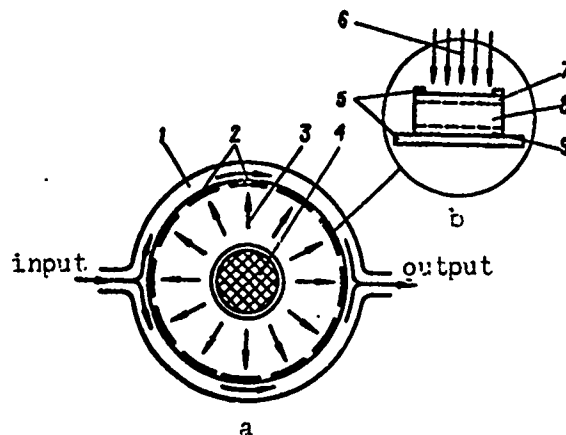


Figure 69. Diagram of the design of a thermophoto converter; a -- thermophoto converter; b -- photo cell; 1 -- cooling jacket; 2 -- photo cells; 3 -- light flux; 4 -- source of radiant energy; 5 -- current lead contacts; 6 -- light flux; 7 -- layer with n-conductivity; 8 -- area with n-or intrinsic conductivity; 9 -- p-semiconductor.

In a thermophotovoltaic converter, the principle of action of which is shown in Figure 69, the radiation of a body 4 which has been heated to a high temperature is converted by photo cells 2 into an electric current. The high efficiency is achieved from the return of the radiation which has not been absorbed by the photo cells to the radiator. This is achieved by optical filters or by the special design of the photo cells with a mirror back point. In such converters, the actually possible efficiency is felt to be 30 percent with a density of 10 watts per square centimeter.

A model of a foreign geranium-based thermophoto converter operating from a radiator with a temperature of 1600° centigrade, with a dropping power density of 0.292 watts per square centimeter, had an efficiency of 4.23 percent. The efficiency could be increased up to 10-16 percent under the condition of increasing the intensity of radiation (the power density) to 3-30 watts per square centimeter.

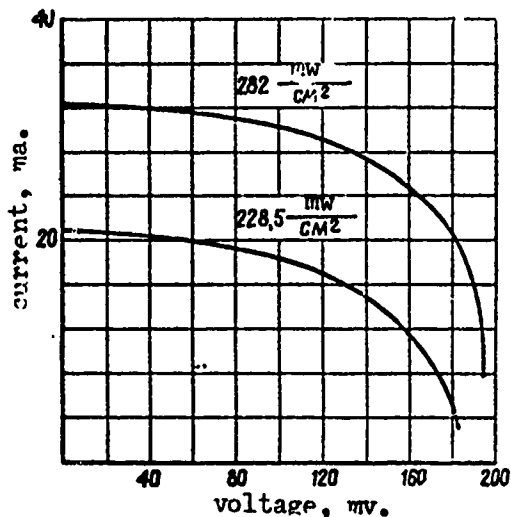


Figure 70. Current-versus-voltage characteristics of the photoelectric converter with various densities of a declining flux of radiant energy.

Figure 70 gives the current-versus-voltage characteristics of a thermophotovoltaic converter. From these it follows that with an increase in radiation, the current produced by the converter significantly rises.

Ferroelectrics

The ferroelectric and piezoelectric sources of current are based upon the effect of the occurrence of emf with the action of the forces of an electric field and a mechanical load on a semiconductor.

The ferroelectrics are a rather large group of semiconductor compounds which differ from other semiconductors in the fact that their internal structure is formed by microscopic areas called domains. These domains possess a definite

electric orientation reminiscent of the magnetic orientation in thermomagnetic materials.

In placing a ferroelectric in an electrostatic field, its domains which have an intrinsic field combine with the internal field, as a result of which the total field assumes a very high intensity significantly surpassing the intensity of the intrinsic field of the domains and the internal field. However, such a field can occur only at a definite temperature below the so-called Curie point. At a temperature exceeding the Curie point, the domains are destroyed and no increase in field intensity is observed.

As ferroelectrics possess a very high amount of permittivity ϵ , the condenser with a dielectric of a ferroelectric material is capable of storing a significant charge. If such a ferroelectric capacitor is charged with an external current source at the Curie temperature, it will have a maximum capacitance. In placing this same capacitor in an area with a different temperature, its permittivity will be reduced, and this will lead to a reduction in the capacitance of the capacitor.

The energy of a charged capacitor is determined by the formula:

$$W = \frac{CU^2}{2}$$

Consequently, with a reduction in capacitance, there will be an increase in the voltage on the capacitor plates (considering the energy stored by the capacitor as fixed), and it will be free to supply a certain quantity of electric energy to the external circuit. With the periodic cooling and heating of a ferroelectric capacitor, an alternating current can be obtained.

Other semiconductors, in applying the mechanical forces of tension and compression to them, disclose a capacity to form different electric charges on the lateral edges. This is called a piezoelectric effect. Among the piezoelectric materials are the Rochelle salt and certain other man-made semiconductor materials in which the piezoelectric effect is expressed more strongly.

The effect of the excitation of an emf with a change in the temperature of the ferroelectric capacitor up to the present has not found an acceptable technical solution making it possible to create a current source. For this reason, only the current sources based upon the piezoelectric effect of ferroelectrics have found practical application.

Until recently, basically Rochelle salt, tourmaline and quartz were used as the piezoelectric elements, but at present they have been replaced by new titanium-based substances, in particular barium titanate which possesses a high piezoelectric constant and good mechanical properties.

If a force varying according to a sinusoidal law with a frequency of 10^4 - 10^5 hertz is applied to a piezoelectric, it is possible to obtain in the piezocell an alternating current with a specific power up to 8 watts per square centimeter.

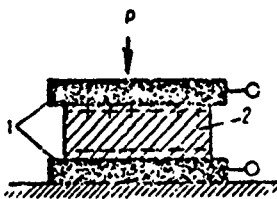


Figure 71. A piezoelectric pick-up
1 -- current conducting plates;
2 -- piezoelectric.

As an example of using the piezoelectric effect for exciting a potential difference, we can give a schematic diagram for the design of a pick-up used in many areas of technology (Figure 71).

The voltage excited on the plates of such a pick-up, under the effect of a mechanical load, is determined according to the formula:

$$U = \delta_0 \frac{P}{C + C_0},$$

where P -- the force in kilograms, δ_e -- the piezoelectric modulus, C -- the capacitance of a capacitor formed by the plates and the piezoelectric plate in farads, C_0 -- the capacitance of the pick-up metering circuit in farads.

Such pick-ups are used for studying high-speed processes, and can be used for exciting brief pulses of electric current in devices activated in striking any obstacle.

Since the current density which can be obtained from a piezoelectric element is extremely low, the voltage on the terminals of a piezoelectric pick-up can be measured only with a tube voltmeter.

The amount of the piezoelectric modulus δ_e for quartz is $2.1 \cdot 10^{-11}$ $1.0 \cdot 10^{-9}$ for barium titanate and $3 \cdot 10^{-9}$ for the Rochelle salt. The use of Rochelle salt in the piezoelectric elements is restricted as a consequence of its low mechanical properties and great hygroscopicity.

Electrets

Electret is the name given to a body which for a long time maintains polarization after the removal of the external electric field and which creates an electric field in the space surrounding it.

In practical terms, electrets are obtained from dielectrics which have been heated to a molten state and held to hardening in a strong electric field. After such an operation, a dielectric becomes the source of an electric field and maintains its charge for a long interval of time.

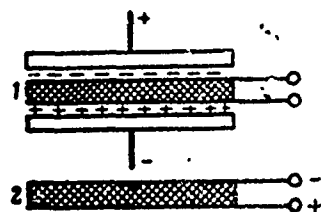


Figure 72. The electret effect; 1 -- molten dielectric cooled to hardening in a strong electric field; 2 -- same dielectric at normal temperature after removal of electric field.

As is known from a physics course, with the effect of a strong electric field on a dielectric, charges of opposite signs are formed in the mass of the dielectric substance (Figure 72). On the side of the dielectric facing the positive electrode, a negative charge arises, and on the side facing the negative electrode, the charge of a positive sign.

The occurrence of a charge in the dielectric by certain scientists has been explained by the piezoelectric effect caused by the deformation of the dielectric under the effect of the forces of the electric field.

The role of the cooling, in the opinion of physicists, consists in the stabilization or, as they say, "freezing in" of the dipoles forming the dielectric. This helps to maintain the charge in the dielectric even with a positive temperature.

As the material for electrets, such dielectrics are used as carnauba wax, amber, organic resins and titanium-based polymer materials. Aside from the electrets which possess the ability to maintain the charge after being present in an electric field, photoelectrets which are polarized under the effect of light are also known.

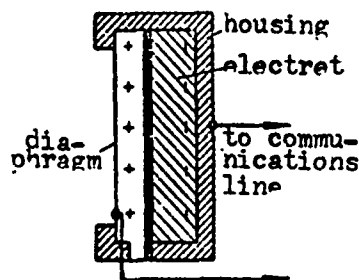


Figure 73. An electret microphone

Since the internal resistance of the microphone equals infinity, it is virtually not influenced by the direct-current resistance of the conductors forming the communications line. However the influence of the conductors, as a capacitance which shunts the capacitance of the microphone, tells on the transmission volume which in the instance of a long line is reduced.

Among the possible areas for using electrets is the focusing of electron beams in various cathode tubes and converters, as well as using the electrets as forces of current for creating a bias voltage in electronic circuits as well as rectifiers.

At present, electret sources of current have not been developed, although there are a number of instruments where electrets in one degree or another play the role of current sources. Among such instruments is an electret microphone the design of which is shown in Figure 73.

Since the internal resistance of the microphone equals infinity, it is virtually not influenced by the

Chapter Four

ATOMIC SOURCES OF CURRENT

Atomic Sources of Current

In Chapter Three we described the thermoelectric and thermoionic sources of current in which the thermoenergy formed as a result of radioactive decay was used as a source of heat. Such a method of using nuclear energy virtually does not differ from the already conventional process of converting the decay energy in a reactor into the thermoenergy of a heat carrier.

In the thermoelectric and thermoionic converters which use the heat of nuclear decay, there are also irretrievable energy losses on radiation, and for this reason the method of the direct energy conversion of the particles formed with radioactive decay into electric energy is very attractive from the standpoint of obtaining maximum efficiency.

In atomic sources of current which use the energy of the particles formed with the decay of radioactive isotopes, use is made both of the method of direct conversion when the particles are captured by a collector and a potential difference is created, as well as methods with intermediate processes, when the particle energy is converted into another type of energy, for example, light energy with subsequent conversion by photoelectric generators.

As is known, with the decay of radioactive substances, aside from the nuclear fragments which possess a maximum energy, gamma rays, beta rays and alpha rays are also formed. Radioactive isotopes with beta radiation are the most suitable for use in portable sources of current, since they do not require the use of thick biological shielding as, for example, isotopes with gamma or alpha radiation which are dangerous for the human organism.

In terms of the principle of action, atomic sources of current can be divided into two basic groups: sources with the direct transfer of charged particles to the electrodes and sources with the intermediate absorption of particles on the p-n junction of semiconductor substances.

In the U.S., the following isotopes are used as sources of radioactive radiation for atomic sources of current. The characteristics of

these isotopes are given in Table 23.

Table 23

Radioactive Isotopes Used in Sources of Current

Type of isotope	type of radiation	density of radiation pcw/cm ²	radiation energy, Mev	half-life, years	shielding
Cobalt-60	γ, β	26	1.33 (γ) 0.30 (β)	5.3	heavy
Strontium-90	γ, β	1.4	0.61	27.7	"
Cesium-137	γ, β	0.23	—	26.6	"
Cesium-144	γ, β	17	—	0.78	"
Promethium-147	β, γ	1.5	0.223	2.26	light
Polonium-210	α	1300	5.293	0.88	"
Plutonium-238	α	3.3	—	86.4	"
Krypton-85	β	—	0.67	10.6	"
Tritium	β	—	0.018	12.26	"
Nickel-63	β	—	0.063	80	"
Carbon-14	β	—	0.0156	5600	"

Note. X-- roentgen radiation.

The atomic batteries in essence are one-shot sources of current. For this reason, the half-life of their active substances. determining the service life, is a very important characteristic. From Table 23 it follows that of the radioactive isotopes given in the table, the least suitable in terms of service life are polonium-210 and cerium-144, although these isotopes have good performance in terms of power density.

The type of radiation emitted by the isotopes, aside from the technical characteristics of the atomic source of current, determines its size and weight, since the biological shielding is chosen from the character of the radiation. For beta and alpha radiation, virtually any solids with a thickness of several millimeters can be used as the biological shielding, but as for the gamma rays, the protection against their effect on the human body is achieved using lead.

From the standpoint of the simplicity of shielding, yttrium is among the most acceptable for use in the atomic batteries.

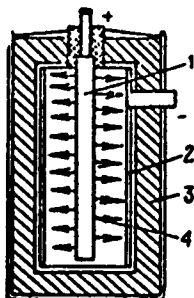


Figure 74. An atomic battery:
1 -- radioactive substance;
2 -- collector; 3 -- biological
shielding (lead); 4 -- direction
of electron movement

The principle of action of an atomic source of current with direct conversion and based upon the direct charge of one electrode relative to the other is given in Figure 74. The plate from a radioactive substance 1 is placed a certain distance away from plate 2 which is the collector of the charged particles emitted by the radioactive substance. As the charge particles accumulate on the collector, a potential difference is established between plate 1 and collector 2. And if beta rays are the source of radiation, then electrons accumulate on the collector, and it acquires a negative charge, while the plate with the isotope is the positive electrode.

Since such an atomic source of current is a capacitor, its maximum voltage will equal the product of the particle charge by the amount of maximum particle energy considering the dielectric properties of the space between the electrodes.

Since the particle energy depends upon the rate of decay of the radioactive substance which is determined by the half-life, for isotopes with a short half-life, where a large number of particles is formed in a unit of time, the current which can be obtained from the element is greater than the current from an element with a long half-life, where the number of particles is less.

For the atomic battery depicted in Figure 74, in the event of using strontium-90 with beta radiation as the radioactive substance, the voltage between electrodes 1 and 2 can reach scores of kilovolts, however, the current of such a battery, considering the long half-life of strontium-90 is very small, 10^{-12} amps. Such batteries can be both vacuum as well as with the filling of the space between the emitter and collector with some dielectric.

The shape of the battery depends upon the placement of the active substance. Generally they are cylindrical in shape. Batteries have also been designed as a hemisphere.

In one of the types of such a battery which has been patented in the U.S., strontium-90 is used as the source of radiation. The space between the electrodes is filled with thermoplastic material. The voltage of the battery is 300 volts, and the current drained into the external circuit is $4.5 \cdot 10^{-12}$ amps.

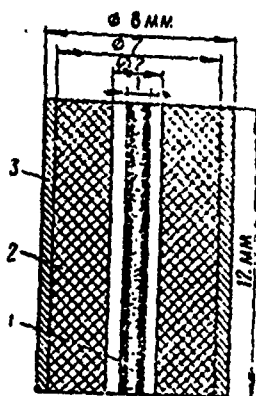


Figure 75. An atomic battery using $\text{Sr}^{90}\text{-Y}^{90}$ isotopes:
1 -- pipe with isotopes; 2 -- polyethylene insulating; 3 -- aluminum collector.

areas, forming a potential difference.

For the atomic sources of current with a semiconductor intermediate converter, 10 percent is considered to be the practically achievable limit of efficiency.

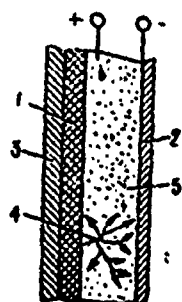


Figure 76. Principle of action of an atomic source of current with the absorption of decay particles in the semiconductor substance:

1 -- radioactive isotopes; 2 -- collector; 3 -- shielding layer; 4 -- movement of electrons and holes under effect of particle energy; 5 -- semiconductor.

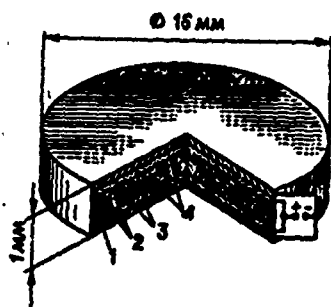


Figure 77. A microbattery:
1 -- promethium-147 isotope;
2 -- luminophore; 3 -- positive layer of silicon photocell; 4 -- negative layer of silicon photocell.

Other atomic batteries with semiconductor converters use the effect of the excitation of a luminophore under the effect of the particles of radioactive decay. This is accompanied by the generation of infrared or ultraviolet rays or visible light. In turn, the radiant energy emitted by the luminophore excites a photoelectric converter, and as a result of this, an electric current arises.

In the literature, such batteries have been described providing for the generation of a current on the order of 20-40 milliamps with a voltage of 1 volt. As a source of radioactive radiation, usually an isotope of promethium-147 is used with phosphorous atoms, since the other isotopes with alpha and gamma radiation destroy the phosphorous and the semiconductor photocells. An atomic microbattery with a photoconverter is depicted in Figure 77. The battery is used for wristwatches and hearing aids and with a voltage of 1 volt produces a current of 2 microamps. The life of the battery is determined by the half-life of the promethium and is around three years.

The above-described atomic batteries do not exhaust the possibilities of using nuclear energy for conversion into the energy of electric current.

The great advantage of the atomic batteries, in comparison with the other sources of current, is the constant readiness for use within the service life, the high reliability, the virtual absence of any dependency of output characteristics upon temperature, and the absence of damage with a short circuit.

Chapter Five

OPERATION OF SOURCES OF CURRENT

The area for handling sources of current should be chosen depending upon the type of sources, their dimensions and quantity. Since a majority of the semiconductor current sources are not meant to be disassembled and repaired, in examining the conditions necessary for providing for the handling of sources of current, we understand the handling of chemical sources of current, that is, storage batteries and certain types of voltaic cells requiring the execution of such operations as charging, filling with the electrolyte, cleaning, repair, and checking the readiness for work.

The requirements for the work area for bringing the unsealed chemical sources of current into a working state consists primarily in providing good ventilation. In charging such batteries as lead, alkaline KN, Zn, KN3 and STs, harmful vapors and gases are generated. These must be removed both in the process of the work as well as with protracted storage, particularly in those instances when the charging and settling area for the storage batteries serves simultaneously as the storage area for small batches of storage batteries. The ventilation of the area should be balanced, and the connecting of the ventilation for the battery area to the general ventilating system is not permitted, while connecting to the chimneys of the building is categorically prohibited.

The air should be drawn out of the area from the upper and lower parts, while the delivery of the air should be at a height of 1.5 meters above the floor so that the fresh air reaches the shelves with the batteries. The fresh air should not contain dust or gases which would harm the sources of current. The exhaust ventilation should provide for the use of motors which do not form sparks in operation, while the ventilator blades should be sufficiently far from the walls of the exhaust pipes for the purposes of preventing spark formation.

The illumination of the area should be chosen considering the creation of normal lighting at the work areas, while the wiring is to be equipped according to the rules provided for damp areas. The ceiling lights should be equipped with glass covers, while the switches should be located outside of the work area. It is prohibited to put plugs and fuses in the battery area. Portable lights should be contained in explosion-proof globes, and wiring should be run in a rubber tube. The area should have emergency lighting.

The heating of the area should provide for the maintaining of a temperature of 15-20° in it, since precisely this temperature provides the best conditions for charging a predominant number of battery types as well as for the storage of the storage batteries and voltaic cells. In the instance of using furnace heating, the firebox of the furnace should be outside of the work room.

The floor in the workroom should have a surface which is resistant to acids and bases (sandstone tile, plastic).

The painting of the walls, ceiling, doors and windows is to be done in gray paint which is chemically resistant to the effect of alkali if the area is designed for handling alkaline storage batteries and voltaic cells, or an acid-proof paint if the area will be used for handling acid batteries. The metallic structures of the shelving and workbenches are grounded by minium and are painted white with a chemically resistant paint, for example, the ML-165 or ML-126 hammer enamel.

The work areas for charging the batteries should have rubber pads regardless of the material of the floor. The presence of a water and sewage system in the work area is also one of the basic conditions for providing convenient and safe work. When it is impossible to bring the water and sewage networks into the area, a tank with water like a drinking tank with a tap should be provided and a bucket for dirty water placed in a special locker with an opening in the lid.

In the area there should be benches for working with the chemical sources of current (filling, saturating and repair), benches for charging the batteries, shelving for storing the batteries, a cabinet for storing chemicals and chemical utensils, a cabinet for storing the electrical measuring equipment and instruments, racks for the connecting and installation wires as well as wires of the metering instruments and a first aid kit.

The tops of the benches for working with the batteries should be covered with vinyl plastic or painted with alkali-resistant paint. The shelves of the shelving should also be painted.

Aside from a first aid kit which should contain everything necessary for providing first aid in the event of cuts, burns and injuries, in the room there also should be a container with boric acid and equipped with a tap or clamped tube, if in the area alkaline sources of current are handled. For an area where acid batteries are handled, there must be the presence of a container with a solution of sodium bicarbonate for neutralizing the acid.

The necessary tools are: a small bench vice, hand vices, an adjustable wrench, a set of socket wrenches with wooden or plastic handles, flat-nosed pliers, wire cutters, a blade, smooth files, a fitter's hammer, a wooden or textolite mallet, a chisel, a hacksaw, a soldering iron and the fittings for it.

Of the special equipment and tools, the following are necessary: a hydrometer, a rubber bulb for removing electrolyte and rubber extension tubes, a medical 20-ml glass syringe for filling miniature batteries, three or four glass or porcelain funnels, porcelain or glass beakers with a capacity of from 0.25 to 2 liters, glass jars with fitted lids for storing chemicals, rubber surgical gloves and rubber mittens, tweezers, a surgical scalpel and a hand jewelers vice.

The range of metering equipment and instruments includes: a battery cell tester, a direct current ammeter with measuring limits of 30 milliamps, 0.3, 3, 10 and 30 amps, a direct current ammeter with the same metering limits, a direct current voltmeter of the 0.5 or 1.0 class with metering limits of 3, 10, 30, 100 and 300 volts (the K-15 or K-45 type), the AVO-5 avometer for the PF-1 tester.

Expendable materials are: cotton cloth, absorbent cotton, acetone, B-70 benzene, ethyl alcohol, paraffin, BF-2 glue, ED-6 epoxy resin, poly-ethylenepolyamine, dibutyl phthalate, distilled water, dichlorethane, solid potassium hydroxide of the A grade or liquid of the C grade (state standard 9285-59), chemically pure potassium hydroxide (state standard 4203-48), lithium hydroxide (state standard 395-57), boric acid and baking soda.

The work of bringing such sources of current as storage batteries into a working condition involves the electric power networks, the use of different strong chemical agents and the execution of mechanical operations. For this reason, the safety rules must be observed.

In working with the power networks, it is essential to bear in mind that a voltage of alternating and direct current above 36 volts is dangerous for human life, and for this reason the handling of live instruments should be done extremely cautiously, particularly if there is only one person in the area. Each time that current is switched on or off only one hand should be used in order to avoid the injuring of vital organs by the current.

Housing and screens, the frames and metal panels of live rectifiers should be reliably grounded. Instruments designed for regulating, switching on and switching off of current should be within easy reach, and their levers should be well insulated. The ends of wires connected to terminals should have caps.

The touching of bare wires or contacts with noninsulated clips of metering instruments is dangerous. The connecting and disconnecting of rectifiers, ammeters and other instruments requiring a discharge of the primary circuit should be done with all voltage completely removed from those elements of the circuit to which the instruments are connected.

The changing of parts in rectifiers and transducers, soldering and adjustments should be made only with the equipment turned off. Here it is necessary to keep in mind, as in the instance of a breakdown of the diodes in transformerless rectifier circuits, the condensers for a long period of time are capable of keeping a charge and this can cause shock injury.

It is categorically prohibited to ground equipment and instruments by the pipes of the water, heating and gas networks. The grounding in the work area should be done according to the rules for grounding of radio equipment.

The connecting of a temporary wire to a live power panel is prohibited as well as working with ungrounded tools (soldering iron, and so forth). The presence of voltage must not be checked by touching with one's fingers.

Soldering irons for working in charging areas should be designed for a voltage of 36 volts. Here such soldering irons cannot be powered from autotransformers. Electric 36-volt soldering irons should be powered from the special low-voltage network or from stepdown transformers. An area where work is being done with connected tools should not left even for a short period of time.

The handling of caustic substances and chemicals used in working with sources of current also requires great care. All chemical agents should be stored in glass, porcelain or special containers equipped with tight lids. The jars should have indelible labels with clear names of the agents and the degree of their toxicity. Poisonous substances should be kept in a separate locker or in a special section of a cabinet which can be locked.

The determining of unknown chemicals by taste or by smelling with the bringing of the open jar up to the nose is categorically prohibited. In order to determine chemicals by smell, the flask or container must be opened the vapors should be directed toward the nose by making fanning movements with one's hand near the mouth. Here the container should be kept at a safe distance. Unknown substances should be sent to a chemical laboratory for analysis.

Such agents as potassium hydroxide or sodium hydroxide or polyethylenepolyamine require particular care in handling. The work of preparing an electrolyte from a solid alkali as well as the preparing of an apoxy glue should be done in rubber gloves and safety goggles. Here the preparation of apoxy glue should be done in a vented hood or in the open air.

The falling of fragments of solid alkali on unprotected areas of the skin causes burns, while the falling of polyethylenepolyamine causes eczema. In the event that alkali falls on the skin of the hands or other parts of the body, it must be washed off with a solution of boric acid (10 percent). In the event that alkali gets into the eyes, they must be flushed with a large quantity of a 3-percent solution of boric acid and then immediately seek medical aid. It must be remembered that an alkali with a density of 1.26-1.40 can cause very severe skin burns and irreversible injury to the eyes.

If polyethylenepolyamine gets on the skin, the afflicted area should be washed well with a strong jet of water, and then washed with warm water and soap. In the event of the reddening of the skin or the development of a rash, medical aid must be sought.

Battery Chargers

Charging rectifiers, electromechanical converters and charging units are classified among charging devices used for charging sources of current.

Modern rectifiers and chargers produced by our industry provide a possibility of charging virtually any chemical sources of current. The nomenclature of the rectifiers is rather extensive, from rectifier units of the VSA type to the automatic rectifiers the VU type and the VAZG and VAKZ charging units.

The rectifiers of the VSA type (selenium rectifier for battery charging) are single phase fullwave rectifiers with adjustable output voltage designed as comparatively small portable boxes weighing 50-55 kilograms. The VSA rectifiers are produced in three types: the VSA-111A designed for a rectified voltage of from 5 to 80 volts and a current of 0.25-8 amps; the VSA-5 with a rectified voltage of from 0 to 64 volts and a load current of 0-12 amps and the VSA-6M with a voltage of 24 or 12 volts and a current of 12 or 24 amps. The latter charger does not have a device for adjusting the output voltage, while the charge current is automatically reduced during the charge depending upon the rise in the voltage of the battery being charged (Figure 78).

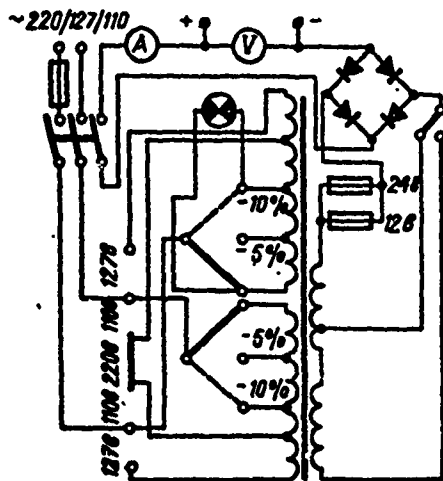


Figure 78. Diagram of VSA6M selenium rectifier

The VU rectifiers are designed for powering communications equipment and are a series of rectifiers designed for a power of 1, 2, 4, 8 and 16 kw. Each series of VU rectifiers has a group consisting of 4 types of VU [rectifier unit]: 24 volts, 60 volts, 120 volts and 220 volts.

All the VU with a power of 1 and 2 kw as well as the VU for powering the anode and filament circuits with a power of 4 and 8 kw are designed for charge and buffer conditions, that is, they can operate with storage batteries under conditions of compensating charging, and can also be used for charging storage batteries. All the remaining types of VU are designed for

use with storage batteries only under compensating charging conditions, and for charging these batteries individual buffer rectifiers must be connected.

The rectifiers of the VU type are designed for operating from a network of 3-phase current, they have been automated and have protection against overloading and overvoltage. The VU provide automatic connecting to a not fully charged battery with current stabilization and a changeover to voltage stabilization with an increase in voltage to a previously set amount.

Table 24

Commercial Rectifiers

1 Тип выпрямителя	2 Характеристики на выходе выпрямителя			3 Габариты, мм			4 Вес, кг	5 Охлаждение
	6 мощность, квт	7 напряжение, в	8 ток, а	9 ширина	10 глубина	11 высота		
VAGZ								
BAГЗ-0,14-8,4/14,8 . .	0,14	8,4/14,8	10	400	300	500	10	natural air
BAГЗ-0,03-8,4/14,8 . .	0,03	8,4/14,8	10	400	300	500	10	"
VAGZB								
BAГЗБ-0,22-37	0,22	37	6	400	300	500	18	"
BAKЗБ-0,56-37/74 . .	0,46	37/74	12,5	400	300	500	40	"
BAГЗБ-0,9-37/74 . . .	0,9	37/74	25	600	500	1000	80	"
BAKЗБ-1,18-37/74 . .	1,18	37/74	60	600	500	1000	85	"
BAKЗБ-1,85/74	1,85	74	25	600	500	1000	105	"
BAKЗБ-1,5-93	1,5	93	12,5	600	500	1000	100	"
BAKЗБ-2,3-93	2,3	93	25	600	500	1000	120	"
VAKB								
BAKБ-1,92-48	1,92	48	40	600	500	1000	110	"
BAKБ-3,7-60	3,7	60	63	600	500	1000	150	forced air
VAKZ								
BAKЗ-4,6-37	4,6	37	125	600	500	1500	200	"

Key:

1. Type of rectifier
2. Characteristics on rectifier output
3. Dimensions, mm

4. Weight, kg
5. Cooling
6. Power, kw.
7. Voltage, v.

9. Current, amps
9. Width
10. Depth
11. Height

Table 24 (con't.)

1 Тип выжимателя	2 Характеристики на выходе выжимателя			3 Габариты, мм	4 Вес, кг	5 Охлаждение		
	6 мощность, квт	7 напряже- ние, в	8 ток, а					
VAKZ	5,5	37	150	600	500	1500	120	forced air
BAK3-5,5-37	5,5	93	63	600	500	1500	200	"
VAKZB	2,3	37	63	600	500	1500	150	"
BAK3Б-5,9-93	6,25	50	125	600	500	1500	265	"
BAK3Б-2,3-37	5	80	63	600	500	1800	200	"
BAK3-6,25-50	6,4	64	100	600	500	1500	270	"
BAK3-5-80	9,6	64	150	600	500	1800	280	"
BAK3-6,4-64	12	64	185	600	500	1800	310	"
BAK3-9,6-64	14	80	175	600	500	1800	325	"
BAK3-12-64	16	64	250	600	500	1800	310	"
BAK3-14-80	18,7	50	375	700	500	1800	450	"
BAK3-16-64								
BAK3-18,7-50								

For Key, see page 157.

The VU have been designed as cabinets 2250 mm high, 700 mm deep and from 450 to 900 mm wide depending upon the power. The VU rectifiers use germanium power rectifiers or selenium rectifiers of the AVS 100 x 100 mm type which permits interchangeability without any adjustment of the VU.

The battery chargers of the VAKZ and VAGZ type for charging acid and alkaline storage batteries are produced by industry for use at power plants and substations, as well as by other users requiring rectifiers with automatic voltage stabilization and automatic current stabilization, with the possibility of conversion from buffer conditions to charging conditions.

The units are designed as cabinets the dimensions and weight of which are determined by the output power. Table 24 gives the types of units with silicon and germanium power rectifiers and their basic characteristics. A schematic diagram of a VAGZ-12/24 unit is given in Figure 79. The VAGZ with a power of 0.03 and 0.14 kilowatts are designed for charging starter batteries.

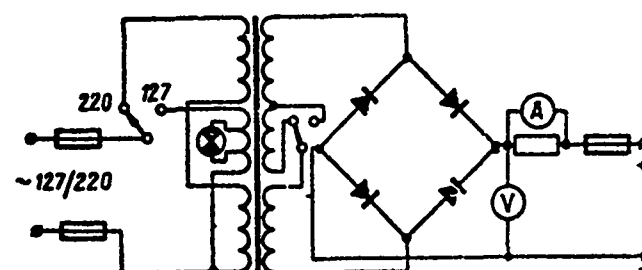


Figure 79. Diagram of the VAGZ-12/24-10-20 rectifier.

The above-indicated rectifiers which are produced by industry are designed for serving a comparatively large battery system. In a number of instances, it is possible to use simpler rectifiers suitable for charging the low-power KN ZhN and KNB storage batteries, the silver-zinc and silver-cadmium batteries, the sealed KN of the D type, TsVK and KNG. The making of such rectifiers can also be done by one's own forces.

Of great interest are the transformerless rectifiers the circuits of which were worked out by S. P. Fursov. The merit of the transformerless rectifier is the extreme simplicity of their manufacture and the high technical and operating characteristics. As a consequence of this these rectifiers (considering their indisputable advantages in size and weight in comparison with similar models of industrial rectifiers) should find wide use.

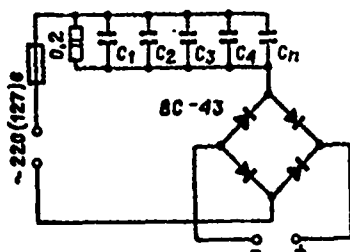


Figure 80. Schematic diagram of transformerless fullwave rectifier assembled according to a fullwave system, for charging storage batteries.

Figure 80 shows the diagram of the simplest transformerless rectifier, while Figure 81 shows a more complicated one with a capacitance voltage divider designed for an output power of 0.5 kilowatts.

In the diagram of Figure 80, the capacitance of the condensers is determined according to the formula;

$$C = 3250 \frac{I_c}{U_n} \text{ microfarads}$$

where I_c -- charge current, and U_n -- network voltage.

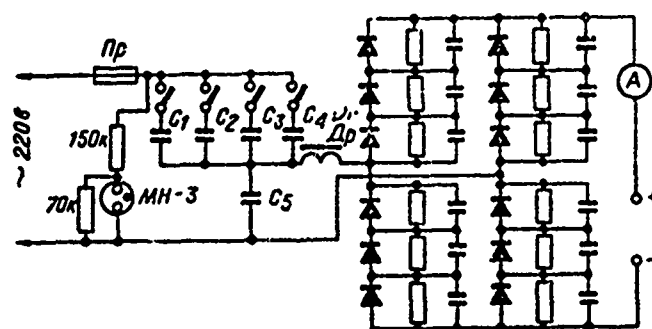


Figure 81. Diagram of a transformerless rectifier with a capacitance divider.

For obtaining a charge current of 2 amps and a network voltage of 220 volts, the capacitance of the battery of condensers will be $C = 3250 \cdot 2/220 = 32$ microfarads.

The rectifier according to the diagram of Figure 81 has a capacitance divider formed by the condensers C_1 , C_2 , C_3 , C_4 and C_5 . The condensers are switched on and off by the appropriate switches, and in this manner the amount of the rectified current is changed. For protecting the rectifiers against breaking with the operating of the rectifier and for improving its output characteristics, there is a choke Dr . The neon lamp on the rectifier input serves as the on indicator and for discharging the condensers after the rectifier has been switched off.

Since the rectifiers used in the rectifiers have a spread in terms of current-versus-voltage characteristics and their inverse resistances are not the same, the rectifiers in series circuits, as occurs in the diagram of Figure 81, have varying inverse voltages. In the event of a breakage of one of the rectifiers, an increased voltage will be delivered to the remaining one. This can lead to the failing of all the rectifiers in the given branch of the rectifier. For this reason, for the purpose of preventing the breakage of the rectifiers, they are shunted with effective resistances. The amount of the shunting resistance rectifier is chosen in such a manner that it not exceed the inverse resistance of the rectifier.

It must be kept in mind that in the transformerless rectifiers it is possible to use only paper condensers of the KGB, MBGP, MBGCh, MBGO and other types. It is impossible to use the various electrolytic condensers in circuits of this type, since with the passage of a high density current, the electrolyte is decomposed and this is accompanied by abundant gas generation which causes a rupturing of the condenser.

More complicated systems using a power transformer and an electronic charge current regulator have been described in the magazine Radio, No 7, 1966.

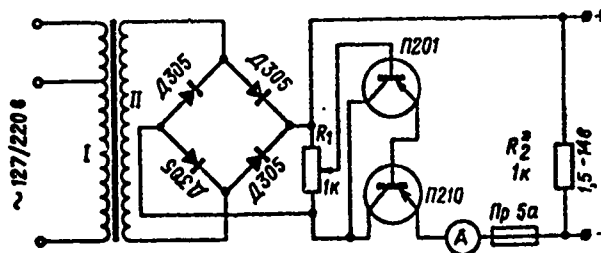


Figure 82. Diagram of a rectifier for battery charging with a rectified current to 6 amps.

In the diagram given in Figure 82, the variable resistor R_1 makes it possible to change the charge current within limits of from 25 milliamps to 6 amps, while resistor R_2 controls the output voltage of the rectifier from 1.5 to 14 volts. The secondary winding of the transformer consists of 45 loops of PEV1.5 wire. The section of the strand is 6 square centimeters. The primary winding for a voltage of 220 volts has 675 loops of PEV0.35 wire. The transistor T_1 is located on a copper or aluminum radiator 3 mm thick with an area of at least 180 square centimeters.

In the diagram given in Figure 83, the transistors have been connected in parallel. This makes it possible to increase the charge current on the rectifier's output to 10 amps. The secondary winding of the transformer is PEV1.87 wire, 82 loops (41 + 41 loops), and sectioned for switching in charging 6-volt and 12-volt storage batteries. The core of the transformer is USh35x35. Winding Ia consists of 323 loops of PEV0.85, and winding Ib from 233 loops of PEV0.63. Winding III is 7 + 7 loops of PEV0.63.

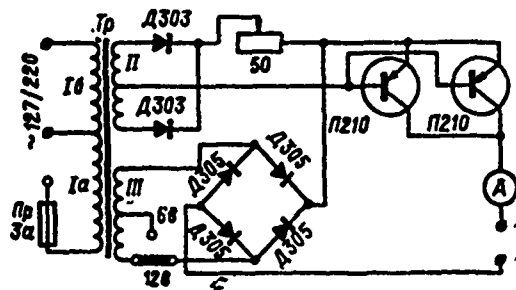


Figure 83. Diagram of rectifier for charging batteries with rectified current up to 10 amps.

For charging small-sized cadmium-nickel storage batteries, industry produces a large number of the most diverse rectifiers. However, a majority of such rectifiers for the purpose of reducing costs have been built according to a halfwave system, and this leads to a reduction in the service life of the sealed circular and cylindrical storage batteries.

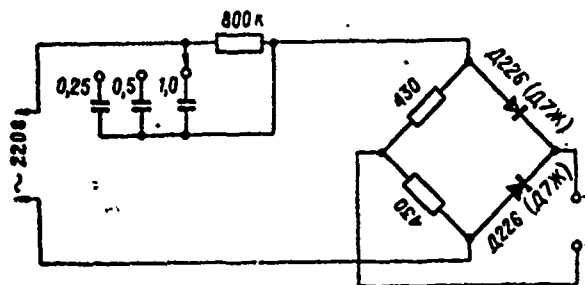


Figure 84. Rectifier for charging sealed plate and cylindrical KN storage batteries with a charge current of 12, 25 and 50 milliamps.

The system proposed by B. M. Plotkin (Figure 84) best meets the requirements of the long operation of the circular and cylindrical sealed batteries. The system is designed for charging the sealed KN cells and storage batteries with a current of 24 milliamps with a 0.5-microfarad capacitor.

By changing the capacitance of the separating capacitor, it is possible to change the current on the rectifier output. An increase in the capacitors capacitance by a whole number provides a proportional increase in current. For example, an increase in capacitance to 4 microfarads, that is, by 700 percent, makes it possible to obtain a charge

current of $24 \times 3 = 192$ milliamps. It is not permitted to use electrolytic capacitors in the rectifier, since it is classified in the transformerless system.

The charging of miniature storage batteries such as the 2x2D-0.1 or the 7D-0.1 can be carried out under field conditions from any DC sources, in particular, from the 12-volt car batteries or the 27-volt aircraft electrical system. For charging the 2x2D-0.1 storage battery from a 12-volt storage battery, a 110-ohm limit resistor must be connected in series into the charge circuit, as is shown in Figure 85. For the 7D-0.1 battery, the charge current of which is 12 milliamps, a 300-ohm resistor is needed.

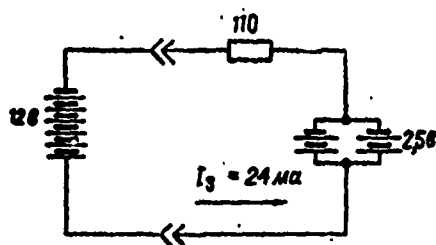


Figure 85. Diagram for charging the 2x2D-0.1 battery from a car battery.

In the above-given instances, the full charging time is 15-16 hours. In the event of necessity, the partially discharged batteries can be given a boosting charge, the time of which is determined by the amount of lost capacitance.

Electrolytes

In modern storage batteries, the following alkaline electrolytes are used.

For the KNB cadmium-nickel lamelless batteries, a summer electrolyte of a solution of potassium hydroxide with a density of 1.19-1.21 with the addition of lithium monohydrate figuring 20 grams of LiOH per liter of solution; the winter electrolyte of a solution of potassium hydroxide with a density of 1.27.

For the nickel-zinc storage batteries, an electrolyte consisting of a solution of potassium hydroxide with a density of 1.18 with the addition of lithium monohydrate figuring 5 grams per liter of solution.

For the silver-nickel storage batteries, an electrolyte consisting of a solution of chemically pure potassium hydroxide with a density of 1.40 or an electrolyte of the same density but with the addition of zinc oxide.

For the silver-cadmium storage batteries, an electrolyte consisting of a solution of chemically pure potassium hydroxide with a density of 1.40.

The electrolyte for the KNB cadmium-nickel lamelless batteries can be prepared from solid potassium hydroxide of the A grade. For this the

pieces of the alkali shaved off with an iron chisel are dissolved in distilled water or rain water, or in water considered fit for drinking by the health inspectorate (in no instance should mineral water, the water from salty lakes or sea water be used) calculating 30 grams of solid caustic alkali per 70 grams of water. Such a solution will correspond to a density of 1.29.

For obtaining an electrolyte with a density of 1.19, 20 grams of solid potassium hydroxide is used per 80 grams of water.

For the KNE lamelless storage batteries, it is also possible to use a liquid electrolyte, the composition of which is given in Table 25. Such an electrolyte has a density of 1.514 which significantly surpasses the density actually used in storage batteries. As a consequence of this, the concentrated electrolyte is diluted.

Table 25

Technical Conditions for Potassium Hydroxide (State Standard 9285-59)

Grade	KOH content, %	impurities, not more, %				
		K ₂ CO ₃ + Na ₂ CO ₃	chlor. (Cl ⁻)	sulf. (SO ₄ ⁻)	iron	sodium hydrox.
Solid, grade A . . .	96	2.5	0.75	0.2	0.03	2.0
Liquid, grade C . . .	50	1.5	0.75	0.2	0.01	2.0

For obtaining an electrolyte of the required density, the liquid electrolyte prepared from the solid K₂Li or the liquid ready-made electrolyte, State Standard 9285-59, is diluted in water in a quantity shown in Table 26.

For example, for obtaining a diluted electrolyte with a density of 1.20 from the ready-made liquid electrolyte, with a density of 1.48, 1.546 liters of water must be added to one liter of the ready-made electrolyte.

For greater convenience in using Table 25, on a sheet of millimeter paper, a family of curves should be drawn in from which it would be possible to easily determine the quantity of water necessary for obtaining an electrolyte of the required density.

In contrast to a majority of electrolytes, the freezing point of which drops with an increase in density, the potassium electrolyte evidences the pattern only to a certain density, and then, with an increase in density, the freezing point of the electrolyte shifts upward, as is illustrated by the data of Table 27. For this reason, in choosing the electrolyte for the KNE batteries, it is essential to be guided by the data for the freezing temperature in Table 27.

Table 26

Preparation of Electrolyte from Concentrated Solutions

Плотность концентрированного раствора KOH при +25° C	Количество воды в г, добавляемое к одному литру концентрированного раствора KOH для получения электролита плотностью					
	1.19	1.20	1.21	1.25	1.26	1.27
1.22	156.7	95.9	45.8	—	—	—
1.23	207.2	144.0	91.6	—	—	—
1.24	267.4	200.8	145.9	—	—	—
1.25	313.3	244.5	187.4	—	—	—
1.26	389.6	296.9	237.5	42.2	—	—
1.27	419.3	344.8	283.3	80.8	36.9	—
1.30	580.7	497.7	429.2	203.8	154.9	113.8
1.357	916	815	733	460	401	352
1.410	1217	1102	1106	690	623	565
1.453	1492	1362	1254	901	825	761
1.483	1686	1546	1430	1050	968	899
1.530	1998	1842	1714	1291	1199	1122
1.563	2222	2055	1917	1493	1365	1282
1.597	2463	2284	2136	1653	1544	1455

Key:

1. Density of concentrated KOH solution at +25°
2. Quantity of water in grams to be added to one liter of concentrated KOH solution for obtaining an electrolyte with a density of:

The addition of the lithium monohydrate to the electrolyte designed for operating the KNB batteries in a temperature range of from -150° C. to +400° C. increases the output of the battery and raises its service life. For this reason, the changeover from the winter electrolyte to the summer one is very desirable.

The electrolyte should be stored in tightly sealed containers, since in coming into contact with the carbon dioxide in the air, potassium carbonates are formed in the electrolyte and these cause an increase in the specific resistance of the electrolyte, and consequently, a reduction in the battery's capacitance. The electrolyte which is in the battery itself must also be protected against coming into contact with air, and with the formation of a white powder, potassium carbonate, around the terminals of plugs, the powder must be removed, making certain that it does not fall into the battery.

The electrolyte for the silver-zinc and silver-cadmium storage batteries is prepared from solid chemically pure potassium hydroxide, State

Table 27

Dependency of Freezing Point of Potassium Electrolyte Upon Density

Density at temperature of +18°	Freezing temperature °centigrade
1.008	-1
1.045	-3
1.092	-8
1.140	-15
1.183	-24
1.239	-38
1.290	-59
1.344	-50
1.399	-35
1.456	-18
1.514	-3

Standard 4203-48. For preparing an electrolyte with a density of 1.40, 485 grams of chemically pure ordinarily granulated potassium hydroxide are taken and dissolved in 550 grams of distilled water with heating and constant stirring until the complete dissolving of the alkali. As the vessel for preparing the electrolyte for the STs and SK batteries, a porcelain vessel should be used or a glass vessel of No 23 and No 32 glass, since the other types of glass, with the effect of a strong alkali, can cause undesirable impurities in the electrolyte.

The obtained solution is filtered through a glass or polyethylene cotton-filled funnel into the containers designed for storage. It is a very good idea to store the electrolyte in polyethylene flasks as is done with the sets for the 3STs25 battery.

The electrolyte prepared in the above-indicated method is the basic one and is used to fill the batteries to be put into use. For topping off a battery which has been in use, an electrolyte with a density of 1.36 is used. For preparing this, 470 grams of potassium hydroxide of the same grade is used for 500-600 grams of distilled water. The prepared electrolyte is checked for density with a hydrometer. It must be kept in mind that the density of the electrolyte in alkaline batteries does not change in the process of charging and discharging the battery. However, in coming into contact with the air, the density of the alkaline electrolyte can alter due to the formation of carbonates, and for this reason a periodic measuring of the electrolyte's density is desirable.

Above it has already been indicated that impurities in an electrolyte used for filling the silver-zinc and silver-cadmium batteries is not desirable. Iron impurities are particularly harmful. For this reason, in preparing the electrolyte from pure alkali, it is essential to take measures to prevent iron from getting into the electrolyte. For the electrolyte of the STs batteries, an iron content of not more than 0.003 grams per liter of solution is tolerable.

Since an increased iron content in the electrolyte tells particularly strongly on the formation of zinc dendrites, the requirements for the purity of the electrolyte remain valid also for a nickel-zinc battery, the service life of which is short due precisely to the formation of electric conducting crosses by the zinc dendrites.

Methods for Charging Batteries

A majority of batteries is charged with a fixed amount of charging current. Here the maintaining of current constancy is achieved by changing the amount of resistance connected to the charge circuit.

The beginning and end amounts of rheostat resistance are determined from the expressions:

$$R_1 = \frac{U_r - n \cdot U_1}{I_{ch}}$$

$$R_e = \frac{U_r - n \cdot U_e}{I_{ch}}$$

where U_r -- rectifier voltage, U_1 and U_e -- voltage in the cell or battery and the beginning and end of the charge, n -- number of cells in the battery, I_{ch} -- charge current.

The rectifier voltage should always be greater than the end charge voltage of the cell or battery.

The end charge voltage is (calculated per cell):

- not more than 2.1 volts for the silver-zinc batteries;
- not more than 2.1 volts for the nickel-zinc batteries;
- 1.60-1.65 volts for the silver-cadmium batteries;
- 1.5 volts for the KNG cadmium-nickel sealed batteries;
- 1.48-1.50 volts for the cadmium-nickel circular and cylindrical sealed batteries.

The charging of the silver-nickel batteries, in comparison with other batteries (KN, SZhN, KNB and others), is more complicated, requires the precise execution of instructions furnished by the manufacturing plants, since otherwise the electrical and operational characteristics are not guaranteed by the plants.

Since the new STs batteries which have not been used do not contain an electrolyte, the first operation to put them into use is soaking. The soaking of the batteries can be done both in a pressure chamber and without it. Soaking in a pressure chamber significantly reduces the overall time for putting a battery into use, since it makes it possible to obtain the required capacitance even in the first cycle. However, in a majority of instances, the soaking of the STs batteries is done at a normal atmospheric pressure.

For soaking, the STs batteries, with the aid of a funnel or special syringe, are filled with the electrolyte up to the level marked by the upper line on the battery's container, and after this the presence of an

emf is checked with a voltmeter. Then the batteries are kept at normal pressure for 10-12 hours and topped off with electrolyte to the level of the upper line. After this they are left with the caps off in a pressure chamber with a pressure reduced to 20-35 mm Hg, where they are kept for two or three minutes. Then the pressure is increased to the normal. Such an operation is repeated five or six times, after which the batteries are topped off with electrolyte up to the level of the upper part, and the batteries are kept at a normal pressure for 8-10 hours.

The soaking without a pressure chamber at a normal atmospheric pressure is carried out for two days with the gradual making up of the absorbed electrolyte, so that at the end of the soaking, the electrolyte level has reached the upper mark.

After the soaking comes the forming of the batteries which is carried out by charging the batteries with a current the amount of which depends upon the type of battery (see Table 19). The duration of the charging is 15-18 hours. During the charging it is essential to keep careful track of the voltage in the individual batteries, particularly toward the end of the charge, in order not to allow an increase of voltage of more than 2.05-2.10 volts per battery.

If during the charging individual batteries have a voltage of more than 2.05 volts before the designated time, the charging must be halted for 2-3 hours, and then continued until the final voltage of 2.1 volts. The charge capacitance in the forming cycle should be 150-160 percent of the rated capacitance of the battery.

After the first forming charge, the batteries are placed in a pressure chamber where they are kept for 2-3 minutes at a reduced pressure for better soaking of the plates. This operation is also repeated 5 or 6 times and, if need be, is accompanied by the topping off with electrolyte to the level of the upper mark.

With the absence of a pressure chamber, the batteries after the first forming charge should be left to stand 12-15 hours. The discharging of the batteries after standing should be with the same current as the charging to a final voltage of 1.0 volts for the battery.

The second forming charge is carried out in the same manner as the first, but the discharge current after standing should be the operating current, that is, the one which will exist in operating the battery. The normal operating charge of the formed batteries or the batteries which have already been used is done with the current of the formed charge until reaching a charge capacitance of 150-160 percent of the rated.

Monitoring of the voltage in the individual batteries, particularly at the end of charging, is essential, since an exceeding of voltage needs the pole reversal of the battery and its failure.

In the process of the charging, it is also essential to watch the temperature, in order to prevent a strong heating of individual batteries. As a rule, this indicates the appearance of a short circuit between the plates. Such batteries are to be immediately disconnected from the charge circuit, since their further charging can lead to the melting of the containers and the leaking of the electrolyte.

The operational charging of the silver-zinc batteries must be done in a current circuit. The parallel connecting of the STs batteries, both in charging and discharging, is not recommended, since individual cells which are undercharged for various reasons begin charging the batteries in the parallel circuit. This causes a disturbance of the charging conditions and can lead to the pole reversal of individual batteries.

As a result of the work done by V. V. Romanov (and other researchers), it has been established that some of the negative qualities of the STs batteries can be eliminated by charging with an asymmetrical current. The charging of the STs batteries with asymmetrical current obtained by shunting the diode in the rectifier with a resistor leads to a significant reduction in the initial voltage with discharging and to an equalizing of the discharge curve. This is explained by the increase in the direct current resistance of the battery occurring as a result of electrochemical processes on the silver electrode under the effect of the asymmetrical current. Charging with asymmetrical current for 20 hours to a final voltage of 2.05 volts leads to a 30-50 percent increase in the service life of the STsD5 and STsD12 batteries. It also eliminates the necessity of carrying out forming charge-discharge cycles for the batteries being put into use.

For putting new batteries into use, it is sufficient to make one charge with asymmetrical current with the same duration as a charge with direct current. Here the capacitance drained in discharging the STs batteries which have been charged with asymmetrical current is increased by 45-60 percent.

According to the data of R. Yu. Bek and N. T. Kudryavtsev, a solid zinc residue can be obtained in imposing an alternating component on the direct current, and with a ratio of the direct current density to the alternating current density of 1:1.7 amps per square decimeter, a solid zinc residue is obtained at a temperature of -30° centigrade, and with a ratio of 1.5:3 amps per square decimeter at a temperature of -50° centigrade. Here it is pointed out that the imposition of an alternating current impedes the development of zinc dendrites. The periodic change in the direction and pulsation of the current with a frequency of 1-2 hertz improves the density of the zinc precipitate on the cathode. The electrolyte is a sodium one.

In the work of V. N. Flerov which is also devoted to the questions of the influence of alternating current on electrode processes in zincate electrolytes, it is pointed out that with a ratio of alternating current density to direct current density of 3:1, the formation of sponge on the zinc electrode is completely eliminated and the precipitate is solid.

Thus, at present the question of obtaining a solid zinc precipitate on the cathode can be considered solved if the processes of charging both the batteries which have zinc as a negative electrode as well as the MTs and VTs voltaic cell of electrochemical systems in addition to the mercury-zinc cells.

For the silver-zinc cells, the following charging conditions with asymmetrical current are recommended. These raise the overall charge capacitance and eliminate the increased voltage at the beginning of discharge. These are given in Table 28.

Table 28

Charging Conditions For Silver-Zinc Batteries With Asymmetrical Current

Type of storage cell	charge current		charge time, hours
	DC, amps.	AC, amos	
STsD CUD3	0.25	1-1.5	30
CUD5	0.5	2-3	28
CUD12	0.5	2-3	30
CUD15	0.8	3.5-5	30
CUD18	1.0	4-6	30
CUD25	1.5	6-8	30
CUD40	2.5	10-13	32
CUD50	3.0	12-15	33
CUD70	5.0	20-25	30
CUD70	3.0	12-15	50
STsM CUM3	0.25	1-1.5	21
CUM5	0.35	1.5-2	21
CUM12	0.5	2-3	19
CUM15	0.8	3.5-5	21
CUM18	0.8	3.5-5	21
CUM25	1.5	7-10	24
CUM50	2.5	10-13	22

One of the diagrams for a device for obtaining asymmetrical current is given in Figure 86.

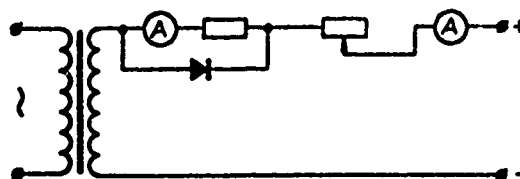


Figure 86. Schematic diagram of a device for charging the STs and NTs batteries with asymmetrical current

The charging of the silver-cadmium batteries, as was pointed out in Chapter Two, is carried out with direct voltage that is, by a current the amount of which is reduced in the charging process. This restriction is also valid for the sealed SK batteries. For the SK batteries with

hermeticity, the charging of which is carried out with open caps, it is possible to use both a graduated as well as a continuous charge with a constant current. Here the total charge capacitance given to the SK battery should be 110-150 percent of its rated capacitance.

The charge of an SK battery should be carried out with as low a current as possible, since the charging with a strong current (in a short interval of time) to a significant degree reduces the discharge capacitance of the SK battery, like, incidentally, the other secondary sources of current.

The voltage at the end of charging should be watched particularly carefully. In the process of charging a SK battery (Figure 4.1), a sharp voltage surge occurs after two or three hours of charging and at the end of the charge in the 11th-12th hour, when the voltage in the battery rises sharply. This voltage surge is the most dangerous, since after the voltage passes 1.6-1.65 volts, gas begins to be produced and the battery container is warped. For this reason, in charging the sealed silver-cadmium batteries, inspection of the voltage at the end of charging is essential as in the case for the silver-zinc ones.

In Chapter Two, the particular features of charging the cadmium-nickel lamelless batteries was pointed out. These features were related to the design of the batteries. It must be kept in mind that the data given in Chapter Two for the time the KN3 batteries are to be left standing with the caps off for venting gases can be reduced in making the charge under graduated conditions.

Graduated charging is carried out in two periods: the first, when the cell or battery is given a charge capacitance equal to 60 percent of its rated capacitance (with a rated charge current), and a second, when the battery is given a charge capacitance equal to 100 percent of the rated, but with a current the amount of which is 100 percent less than the rated charge current.

The graduated system must be used in those instances when full capacitance must be obtained from the battery, as well as in those instances when a fall in capacitance from cycle to cycle is suddenly discovered.

A battery which has lost a portion of its capacitance must be charged with a so-called leveling charge the essence of which is a protracted charge with a low-density current of not more than 3-5 percent of the rated capacitance of the battery. Here the battery should store at least 200 percent of its rated capacitance. The leveling charge also helps in the more complete reduction of the active substances of the battery.

In a number of instances, a battery must be charged in a short interval of time. The express charging of the KN3 cells and batteries is done with a current which is 100-200 percent greater than the rated. Here,

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the charge capacitance should be around 200 percent of the rated. Since the express charging conditions have a bad effect upon the output of the batteries and lead to a reduction of service life, after several express charges, leveling charges should be made with a measuring of capacitance on the control discharge cycles with a discharge current that is the rated one for the given battery.

Leaving batteries of the KNbN type to stand for 24 hours after charging for the venting of gases is obligatory, since otherwise the containers of the batteries can rupture.

The charging of the same KN batteries is best done at a temperature of $+5^{\circ}$ to $+35^{\circ}$ centigrade, since charging at a reduced temperature leads to the failure to reach charging capacitance, and at an increased temperature, the service life of the batteries is reduced.

The discharging of the KNb batteries, particularly those which are operated with blind charging plugs, should be carried out to a voltage of not lower than 2 volts.

Charging and Regenerating Voltaic Cells and Batteries

The Finnish manganese-zinc battery which has recently been developed by our industry, aside from high specific characteristics providing a long discharge time, possesses one other significant property, the capacity for overcharging. The technical conditions for the Finnish battery guarantee an output of 10 percent of the rated capacitance with the last 20-25 overcharges. However, the ability to produce capacitance after charging is also possessed by the widely used FBS, KBS, "Krona" and other batteries and cells under the condition that the recharging is done within the shelf life of the cell or battery, as well as under the condition of the absence of damage to the zinc cup or the insulating casing of the cell. The charging of manganese-zinc cells and batteries is done with asymmetrical current providing for a solid zinc precipitate on the negative electrode.

There are several systems for obtaining asymmetrical current. The simplest diagram of a rectifier for charging the VTs and RTs cells and batteries is given in Figure 37. The more complicated systems proposed by V. V. Romanov (Figure 38) are also designed for using a stepdown transformer with an output voltage of 7.5 volts. This makes it possible to use them for charging a battery with a voltage of 4.5 volts and lower. One of the diagrams (Diagram a) uses a diode shunted by a small resistor for passing the alternating component. A 3.5 volts, 0.28 milliamperes bulb connected to the charging circuit serve as the current stabilizer and simultaneously performs the role of the battery end-of-charge indicator. The end is determined from the reduction in the brightness of the filament.

Another system (b) for obtaining asymmetrical current uses two opposing diodes. In this system, the end of the battery charging is

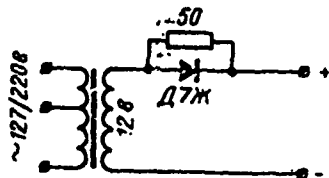


Figure 87. Diagram of very simple device for charging MTs and RTs cells and batteries with asymmetrical current

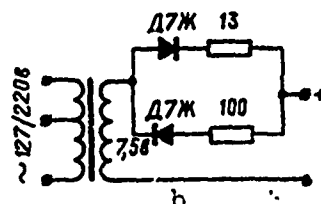
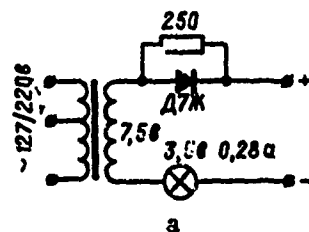


Figure 88. Diagram for charging MTs cells and batteries with asymmetrical current; a -- with indicator; b -- with balancing circuit

determined from the stop of the voltage increase which after reaching 6 volts (for the K3S batteries) no longer rises as a consequence of equalizing: the current in both parallel branches and the flowing of only the variable components which does not cause an increase in voltage.

In using these systems, in the process of charging it is essential to watch the voltage of the direct current as well as the alternating component. The charging of the K3S batteries which have been discharged below 2.3-2.4 volts is continued using the described devices for 12-14 hours in order to give the battery 140-160 percent of its capacitance.

A system proposed by Ye. Gumel' does not have a stepdown transformer and is powered by the 127/220-volts AC system (Figure 89). The condensers C_1 and C_2 should stand a voltage of 250 volts. The condensers can be replaced by 4.7-k [coulombs] resistors with a power of 4 watts. The system is designed for recharging batteries which have been partially discharged but not more than to a voltage of 1.1 volts per cell, since charging with such a system envisages the reduction of MnOCH to the positive electrode by the oxidation of MnOCH into MnO_2 .

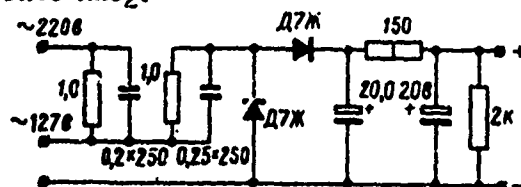


Figure 89. Rectifier for recharging FBF, K3S, "Krona" and other cells and batteries.

The regeneration of wornout pancake cells can be carried out according to a method proposed by Ye. Shestakov where the disc blocks are boiled in solution of sal ammoniac (150 grams of NH_4Cl per 500 grams of water). The blocks are boiled until the discs swell, after which they are cooled in cold water, wiped dry and again tied up for packing in a battery. After packing, the battery is formed and this consists of charging with a direct current for 2-6 minutes. Here the source of current should have a voltage which exceeds voltage of the charged battery by 20-30 percent.

Another method for partially restoring the operability of cup-type cells and batteries consists in drilling several openings in the cup of the cells for allowing air oxygen to reach the manganese electrode. Under field conditions, the cups with openings can be submerged for several minutes in water for wetting the dried-out electrolyte. Of course, cells after such primitive regeneration do not work for a long time, but they will be usable for a certain period of time.

Certain Malfunctions of Batteries and Ways to Eliminate Them

In the process of operating batteries, various disruptions of their work occur related either to negligent handling and deviations from the established instructions or to unforeseen circumstances when the source of current goes out.

The basic types of disturbances in the normal work of batteries and the methods for eliminating them are given in Table 29.

Repair of Lamelless Cadmium-Nickel, Silver-Zinc, Sealed Circular and Cylindrical Batteries

In the case of the failure of a battery due to the rupturing of the plates from the pole terminals, an internal short circuit due to a breaking of the separation, the falling of metal articles into the battery or the formation of sediment (sludge) which cannot be removed by washing, the battery must be disassembled, and for this the top must be separated from the housing.

The method from separating the top from the housing depends upon the material of the vessel.

For metal battery vessels, the possibility of repair with the removal of internal defects is determined by the presence of welding equipment in the shop. The tops of batteries which are to be disassembled are cut along the welded seam until the appearance of the joint between the top and the housing. After this the top with the plate assembly is extracted from the container.

The tops of plastic vessels are removed either with a fine cutter or with a sharp thin blade made from a saw blade.

Table 29
Certain Malfunctions of Alkaline Storage Cells and Ways to Eliminate Them

Character of malfunction and type of cell	Type of malfunction	Way of elimination
No voltage on battery terminals. KN, ZnN, KNE, D, TsNK	No contact in connections between cells Absence of electrolyte Short circuit between plates or plate blocks	Tighten nuts on connector, solder bar Fill up with electrolyte Turn over cell for repair
Increased self discharge KN, ZnN, KNE, D, TsNK, KNG	Short circuit on surface of top and through insulating gasket. Salt leaks through bridges. Impurities in electrolyte	Inspect and clean top, replace gasket, clean top and leads of salts Change electrolyte
Capacitance losses. KN, ZnN, KNE, STs, D, TsNK, KNG	Low electrolyte level Systematic undercharging Short circuits and current leaks Harmful impurities in electrolyte	Check plugs, add electrolyte Balancing charging Same as for self-discharge Change electrolyte
Rapid formation of crawling salts KN, ZnN, KNE, D, STs, TsNK	Bad fit of terminals High electrolyte level High electrolyte density Poor sealing of top	Tighten terminal nuts Remove electrolyte Add water Clean top and ... it with HF-2 glue
Poor operation at low temperatures KN, ZnN, KNE, D	Low electrolyte density Excess potassium carbonate in electrolyte, systematic undercharging	Change electrolyte Make two forming charge-discharge cycles
Generation of foam. KN, KNE, STs	Impurities of organic matter in electrolyte	Change electrolyte

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Table 29 (Con't.)

Overheating of connectors and terminals KN, KNB, STs	Poor contact in terminals High electrolyte level Short circuits between plates	Clean connector Remove electrolyte Turn over for repair
Warping of container KN, KNB, STs, D	Charging with blind plugs or closed ventilating openings, tight washers on plugs Excessive charge current (D)	Screw out plugs, clean channels, replace rubber washers Hold circular battery in insulating gaskets in a vise and make two charge- discharge cycles gradually tightening the vise.

After eliminating the malfunction, the top of the metallic vessel with the plate assemblies is carefully placed back in the container and carefully welded along the seam of the top. Here it is essential to avoid overheating the other parts of the battery, particularly the lower portion where the separation is in contact with the housing. In the lamelless battery where the plates are fastened to a common bridge, the plates which have become loosened are connected to the bridge only by welding, since in the case of soldering with copper or silver, the point of connection is quickly destroyed under the effect of corrosion.

After careful inspection of the plate assemblies, the areas with damaged separation are found and replaced with a new separation, while the destroyed polyamide fiber is replaced with new fiber of the same section (it is possible to use fishing line). If there is an insoluble residue of sludge on the bottom of the containers, it is removed with a metal brush, and the containers are washed out well and dried. The plate assemblies after the elimination of damage are also washed well in running water and dried thoroughly and for this the plates are slightly spread apart in a fan shape.

The plastic containers of the lamelless and silver-zinc batteries from organic glass and polystyrene are connected to the tops with a glue consisting of a 1 percent solution of organic glass or polystyrene in dichlorethane. Epoxy glue is used for other plastic, with the exception of fluorine plastic (see appendix 2)

It must be kept in mind that the surfaces to be glued should be carefully cleaned of dirt and grease. The cleaning of the surfaces is done with acitone, pure B-70 benzene (or Kalosha) or alcohol depending upon the material to be glued. The containers and the tops from organic glass or polystyrene in no instance should be degreased with dichlorethane, since the surfaces are partially dissolved and "melt."

For glueing articles from PTFE, polyethylene and certain other types of plastics classified in the group of nonpolar materials, the surfaces of these plastics which are to be glued are subject to heat treating and cleaning with a sand-blasting unit, after which a thin layer of AK-20, 88 or VKT-3 glue is applied.

The repair of silver-zinc batteries consists in going through the plates and removing the loosened zinc electrodes and destroyed separation on those plates where damage has occurred as a consequence of a short circuit across the dendrites in the form of dark fused points with a halo. If the plates have not been destroyed and only the separation has been damaged, it must be replaced, and for this the pair of plates is wrapped with a new separation from cellophane or acetate film which has first been soaked well in water. Here the number of film layers must be kept the same. If there is no roll cellophane or acetate film of the necessary thickness, the wrapping of the plates for small-sized STs batteries can be done with cellophane used to package food products.

In the case when one or several plates has failed and the remainder are in good condition, the damaged plates must be removed, and for this the cluster of current leads from the terminal must be unsoldered. Before unsoldering the terminal current leads, the top of the battery is removed in order not to warp the top with the heat. The damaged plates are replaced in the assembly with good ones from another disassembled battery or with new ones. The plates from a previously used battery must be washed well in distilled water.

The repairing of sealed batteries (KNG, TsNK and circular ones) it is possible only in the instance where their hermiticity has not been destroyed. Sometimes batteries are encountered which do not take a charge and their repair is virtually impossible. But in a number of instances the sealed batteries can almost be completely regenerated. Such instances include the restoring of deeply discharged batteries, batteries which have not been in use for a long time or batteries which have been subjected to a short circuit. The batteries which have suffered as a consequence of the designated factors can be restored by a periodic charge with a low current which is approximately 100 percent less than the rated charging current. After each regenerating charge, a charge with a rated current is given. The operation is repeated several times until the rated capacitance of the cell or battery is restored.

The connecting of the buses in the batteries composed of sealed plate cells or TsNK cells is done by soldering the buses to the housing or to the top of the batteries. However protracted heating of the housing or top leads to the disintegration of the gasket and the breaking of the battery's seal. For this reason, soldering the buses to the top of the circular sealed batteries can be done only under the condition of good heat dissipation, for example, in the following manner.

The battery is placed in a flat container with water in such a manner that the water level reaches the shoulder of the battery. A thin layer of flux is applied to the top of the battery, after which a drop of solder is applied to the top using the soldering iron with the tip not closer than 2 mm. The top is immediately cooled with a rag which has been soaked in water or with a small brush. The previously tinned bus from thin sheetiron, copper or brass is applied to the dry drop of solder on the top, after which it is heated with the iron until the complete melting of the solder and the firm attachment of the bus to the top. As soon as the bus is in place, it is essential to quickly cool the soldering point and wipe it dry.

The soldering of a new bus to the housing of a circular battery is best done on the shoulder of the battery, since soldering to the bottom, as a rule, causes gas generation and the breaking of the battery's seal. For soldering a previously-tinned bus to the shoulder of a battery held in an ordinary clothes wringer and submerged in water, a thin layer of solder is applied with the rapid movement of the soldering iron. The bus is given a shape conforming to the cross from the lateral surface of the battery to the shoulder, after which the bus is held against the tinned point on the

shoulder and the required layer of solder is applied with the iron.

The soldering of new buses to batteries of the TsNK type is also done under the conditions of good heat dissipation.

Thus, it is possible to replace nonfunctioning cells in a 7D-0.1 battery. The top in the battery can be glued with polystyrene glue. The 3F-2 glue is not suitable for this purpose.

The above-described soldering method can be used to assemble cells into a battery for the necessary voltage. Since the soldering method does not provide sufficient strength from the fastening of the bus, a battery assembled from individual cells must be placed in a suitable casing or wrapped well with sticky polystyrene tape and then placed in a cardboard casing impregnated with water-proof glue of the 3F-2 type.

Appendix 1

TABLE OF ELECTROCHEMICAL POTENTIALS

1) В кислых растворах		2) В щелочных растворах	
3) Электрохимическая система	Потенциал, В	3) Электрохимическая система	Потенциал, В
$\text{Li} \rightarrow \text{Li}^+ + e$	-3.045	$\text{Ca} + 2\text{OH}^- \rightarrow \text{Ca}(\text{OH})_2 + 2e$	-3.03
$\text{Ba} \rightarrow \text{Ba}^{2+} + 2e$	-2.90	$\text{Mg} + 2\text{OH}^- \rightarrow \text{Mg}(\text{OH})_2 + 2e$	-2.89
$\text{Ca} \rightarrow \text{Ca}^{2+} + 2e$	-2.87	$\text{Al} + 4\text{OH}^- \rightarrow \text{H}_2\text{AlO}_3 + \text{H}_2\text{O} + 3e$	-2.35
$\text{Na} \rightarrow \text{Na}^+ + e$	-2.71	$\text{Si} + 6\text{OH}^- \rightarrow \text{SiO}_3^{2-} + 3\text{H}_2\text{O} + 4e$	-1.70
$\text{Mg} \rightarrow \text{Mg}^{2+} + 2e$	-2.37	$\text{Zn} + 4\text{OH}^- \rightarrow \text{ZnO}_2^{2-} + 2\text{H}_2\text{O} + 2e$	-1.216
$\text{Al} \rightarrow \text{Al}^{3+} + 3e$	-1.66	$\text{Fe} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2 + 2e$	-0.877
$\text{Mn} \rightarrow \text{Mn}^{2+} + 2e$	-1.18	$\text{I}_2 + 2\text{OH}^- \rightarrow 2\text{H}_2\text{O} + e$	-0.828
$\text{Si} + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 4\text{H}^+ + 4e$	-0.86	$\text{Cd} + 2\text{OH}^- \rightarrow \text{Cd}(\text{OH})_2 + 2e$	-0.810
$\text{Zn} \rightarrow \text{Zn}^{2+} + 2e$	-0.763	$\text{Mn}(\text{OH})_2 + 2\text{OH}^- \rightarrow \text{MnO}_2 + \text{H}_2\text{O} + 2e$	-0.05
$\text{Fe} \rightarrow \text{Fe}^{2+} + 2e$	-0.440	$2\text{Ag} + 2\text{OH}^- \rightarrow \text{Ag}_2\text{O} + \text{H}_2\text{O} + 2e$	+0.344
$\text{Cd} \rightarrow \text{Cd}^{2+} + 2e$	-0.402	$4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4e$	+0.401
$\text{Pb} + \text{SO}_4^{2-} \rightarrow \text{PbSO}_4 + 2e$	-0.356	$\text{Ni}(\text{OH})_2 + 2\text{OH}^- \rightarrow \text{NiO}_2 + \text{H}_2\text{O} + 2e$	+0.49

Key:

1. In acid solutions
2. In alkaline solutions

3. Electrochemical system
4. Potential, volts

Appendix 1 (cont.)

1) В кислых растворах		2) В щелочных растворах	
3) Электрохимическая система	Потенциал, ϕ	3) Электрохимическая система	Потенциал, ϕ
$Pb \rightarrow Pb^{2+} + 2e$	-0.126	$Ag_2O + 2OH^- \rightarrow 2AgO + H_2O + 2e$	+0.57
$H_2 \rightarrow 2H^+ + 2e$	-0.000		
$Ag + Cl^- \rightarrow AgCl + e$	+0.222		
$Cu \rightarrow Cu^{2+} + 2e$	+0.337		
$H_2O_2 \rightarrow O_2 + 2H^+ + 2e$	+0.682		
$Ag \rightarrow Ag^+ + e$	+0.799		
$2H_2O \rightarrow O_2 + 4H^+ + 4e$	+1.229		
$Mn^{2+} + 2H_2O \rightarrow MnO_2 + 4H^+ + 2e$	+1.23		
$2Cl^- \rightarrow Cl_2 + 2e$	+1.36		
$PbSO_4 + 2H_2O \rightarrow PbO_2 + SO_4^{2-} + 4H^+ + 2e$	+1.685		
$2H_2O \rightarrow H_2O_2 + 2H^+ + 2e$	+1.77		
$Ag^+ \rightarrow Ag^{2+} + e$	+1.98		
$2F^- \rightarrow F_2 + 2e$	+2.87		

Key: [See page 180.]

Appendix 2

Glues and Resins Used For Repairing Battery Containers

BF-2 glue for glueing glass, porcelain and rubber to plastic (except polyethylene and thermoplastic material), and rubber to metal.

Glue for organic glass -- a solution of organic glass in dichlorethane (0.5-1 percent).

Glue for polystyrene -- a solution of polystyrene chips in dichlorethane (2-3 percent).

Epoxy resin (epoxy glue) for glueing plastic, rubber to plastic and metal, and metal plastic (except fluorine plastics).

A resin which polymerizes at room temperature is prepared in the following manner. Formula: 100 parts by weight of ED-6 resin, 20-25 parts by weight of dibutyl phthalate (plasticizer), and 12-14 parts by weight of polyethylenepolyamine (hardener).

The resin is heated to 80° and just one-third of the amount of plasticizer is put in, after which heating continues at the same temperature for an hour. Then the mass is cooled to room temperature and the rest of the plasticizer and hardener are put into it. The entire mass is energetically mixed until obtaining a semiliquid consistency of a uniform color. Final polymerization occurs 24 hours later.

Another type of epoxy resin is polymerized at a temperature of 90-120°. As a consequence of this, this resin can be used for glueing plastics which have sufficient temperature resistance. Its formula: 100 parts by weight of ED-5 or ED-6 resin, 35-40 parts by weight of maleic anhydride.

The preparation procedure consists in heating the resin at a temperature of 80° and putting in the maleic anhydride. After this the mass is stirred until a uniform color is reached. Final polymerization occurs after 1.5-2 hours.

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